

# Replacing Fuel With Solar Energy

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## The Right Place for Solar Energy

Harvesting solar energy at South Pole can reduce the fuel consumption needed to produce electricity. The busiest season at South Pole is the summer season, which is also the period of constant daylight. The sun rises on September 25<sup>th</sup> and sets around March 20<sup>th</sup>. During this time, the sun circles through all four horizons but never sets. The weather is mostly clear. According to the sun card data collection during 9/07 and 3/08, there are 3272 sunny hours out of 4224 total hours. White snow has a very high albedo (reflectance index) so that short-waved irradiation is reflected into all directions increasing the input on the solar panels. Further, photovoltaic panels work best when being cooled. Therefore, the South Pole environment is an optimal place for utilizing solar panels.

## Proof of Technology

Based on the John Rand and Christopher Williams 2000 Study: Evaluation of Photovoltaic Panels at the South Pole Station, photovoltaic panels are capable of enduring the harsh climate conditions at South Pole. Several panel manufactures were tested for mechanical and electrical characteristics. The inspection showed that the PV panels were not noticeably degraded during the 410-day exposure. The electrical performance of the PV panels depended on sun angle (azimuth) and visibility. The panels approached their highest outputs when the sun reached its highest azimuth and when the visibility was high.

## 2008 Installed PV Test Station

The new testing station consists of 6 panels installed on top of the Alti Meadows building (Summer Camp): 1 horizontal panel, 2 panels facing east, 1 panel facing north, 1 panel facing west, and 1 panel facing south.



The system consists of the PV panels, individual micro-inverters, and energy management unit. The installed panels are mono-crystalline NT-R5E3E 175 W Sharp panels with anti-reflective coating and BSF (Back Surface Field) structure to improve cell efficiency. The modules incorporate bypass diodes to minimize power drop caused by shading. The shielding consists of white tempered glass, EVA resin and weatherproof film along with aluminum frame for extended exterior use. The multi-contact output leads have weatherproof connectors.

The Enphase Micro-inverter M175 maximizes the energy production from the PV panel. Each panel has its own micro-inverter such that an individual Maximum Power Point Tracker (MPPT) controls each PV module. This insures that the maximum power available from the panel is exported to the utility grid regardless of the performance of other PV modules in the array. The result is maximum energy production from the system. There is no string calculation necessary and the PV modules can be installed in any combination of module quantity, type, age and orientation. The M175 Micro-inverter works with most 72-cell PV modules. It converts the DC panel output to an AC current (typically 240V).

Currently, the inverters are installed exterior on the back of the PV modules. Even though the inverters comply with NEMA 6 rating standard for outdoor use and are insulated, they should be moved inside to be protected from extreme cold temperatures.

The Energy Management Unit (EMU) communications gateway is installed inside the building. The EMU provides an Ethernet connection and reports to the Enphase Enlighten web server. The Enlighten software presents current and historical system performance trends, and it informs the operator when the PV system is not performing as expected.

**Panel Parameters**

Sharp Solar Panel MP W	175
# Panels	6
Total Installed kW	1.05
Panel Length mm	1575
Panel Width mm	826
Panel Area sq ft	14
SolarPower SystemCost \$/kW	7000

**Panel Electrical Parameters**

Open Circuit Voltage V	44.4
Short Circuit Current A	5.4
Voltage at MPP V	35
Current @ MPP A	4.95
Max Fuse A	10

**Purpose of the PV Testing System**

The energy produced is used for the support of the building's electricity demand. The data collected by the Enlighten web server can be used to evaluate the PV modules' performance throughout varying solar azimuths, visibility and temperatures.

### Direction of Installed Panels – Horizontal vs. Vertical:

Since each panel has its individual Micro-inverter, the PV panel performance can be evaluated for each orientation: Horizontal, grid north, east, south, and west.

It is expected that the performance of the horizontal panel will vary greatly with the changing sun azimuth (from 0 DEG to 23 DEG to 0 DEG). Even though the horizontal panel is always exposed to the sun, it never reaches its maximum power point MPP due the low sun azimuths. PV panels reach their MPP when the sun is shining directly at the surface (80-90 DEG angle). The retrieved data confirm this assumption. The horizontal panel's output seems to never exceed half its MPP (175W).

The vertical installed panels are reaching their MPP whenever the sun shines at them with an angle close to 80-90 DEG. This happens once a day for each orientation. The collected data seems to prove the fact that the vertical PV modules produce power even when the sun is not directly shining at them. This is caused by the snow reflection that provides a large amount of indirection irradiation, which is captured by the vertical panels. The measured energy data seems to suggest that the vertical installed panels provide a higher energy output. There are also variations in the energy output between different vertical orientations. This particular phenomenon however, still needs to be investigated as there is no simple explanation for it.

### Energy Produced by the Test System

Since it's start-up on January 8<sup>th</sup>, the system has produced about 65 kWh weekly. The produced power varies for each direction as shown in the table below:

Direction	North	East- Panel1	East-Panel2	South	West	Horizontal
Weekly kWh	9.68	10.68	10.5	10.38	8.69	9.28

It is estimated that system would be capable of producing 1554 kWh during the 176 days of sun light. **(This and the following will have to be updated once all data is retrieved for Jan-March 09 – it will probably be less than estimated)**

This estimate is based on the currently produced energy during sunny days as well as the sun card data retrieved during 2007 and 2008. The sun card data provides information about visibility and cloudiness that reduces the number of the sunny hours based on the overall sun hours available (176 days x 24 hours). According to the sun card data set, there were 3272 sunny hours out of 4224 possible hours during September 2007 and March 2008.

6 Modules Installed in the following arrangement:	Prod. kWh per sunny day	Sunny hours during Sep. 07	Sunny hours during Oct. 07	Sunny hours during Nov. 07	Sunny hours during Dec. 07	Sunny hours during Jan. 08	Sunny hours during Feb. 08	Sunny hours during Mar. 08	Predict. kWh during 7 months summer season	Actual kWh during 7 months summer season
As is (1Up, 2East, 1West, 1North, 1 South)	11.4	157.4	415.8	634.1	606.4	646.1	487.4	325.1	1554	1577.0
6 x Up (Alternative 1)	10.2	157.4	415.8	634.1	606.4	646.1	487.4	325.1	1391	1478.4
6 x North (Alternative 2)	11.4	157.4	415.8	634.1	606.4	646.1	487.4	325.1	1554	1636.8
6 x South (Alternative 3)	10.2	157.4	415.8	634.1	606.4	646.1	487.4	325.1	1391	1436.2
6 x West (Alternative 4)	11.4	157.4	415.8	634.1	606.4	646.1	487.4	325.1	1554	1552.3
6 x East (Alternative 5)	12	157.4	415.8	634.1	606.4	646.1	487.4	325.1	1636	1584.0
6xSun Tracking 1-axial (Alternative 6)	25.92	157.4	415.8	634.1	606.4	646.1	487.4	325.1	3534	

The table above compares the installed system to 6 alternative setups. The first 5 alternatives assume that all of the 6 panels would be installed facing the same direction: one direction for each alternative. The expected result would be that all vertical orientations produce similar outputs, however they should produce more than the horizontal setup based on the low sun azimuths. (Explained further under 'Purpose of PV System'). This seems to be true except for alternative 3, which produces equally less for the south facing setup as the horizontal setup.

Alternative 6 assumes a single-axial sun tracking setup, which would automatically (via photocell) rotate the vertical aligned panels to track the sun's travel through the horizon. It is assumed that the panels always reach their MPP due the unchanged alignment with the sun. Utilizing sun tracking systems involves extra equipment, however, less than half the PV panels are needed to achieve the same output compared to a fixed system.

### Proposal for Replacing Fuel by Solar Energy

The exterior surfaces (roofs and facades) of the existing buildings at South Pole offer a considerable area that could be used to install PV modules. The table below lists all buildings with flat roofs and provides information of the individual roof area as well as the estimated usable area. It further determines how many solar panels of the Sharp 175W type would fit on the roof assuming an arrangement in rows. It is estimated that a total of 1916 panels could be installed on top of the Elevated Station.

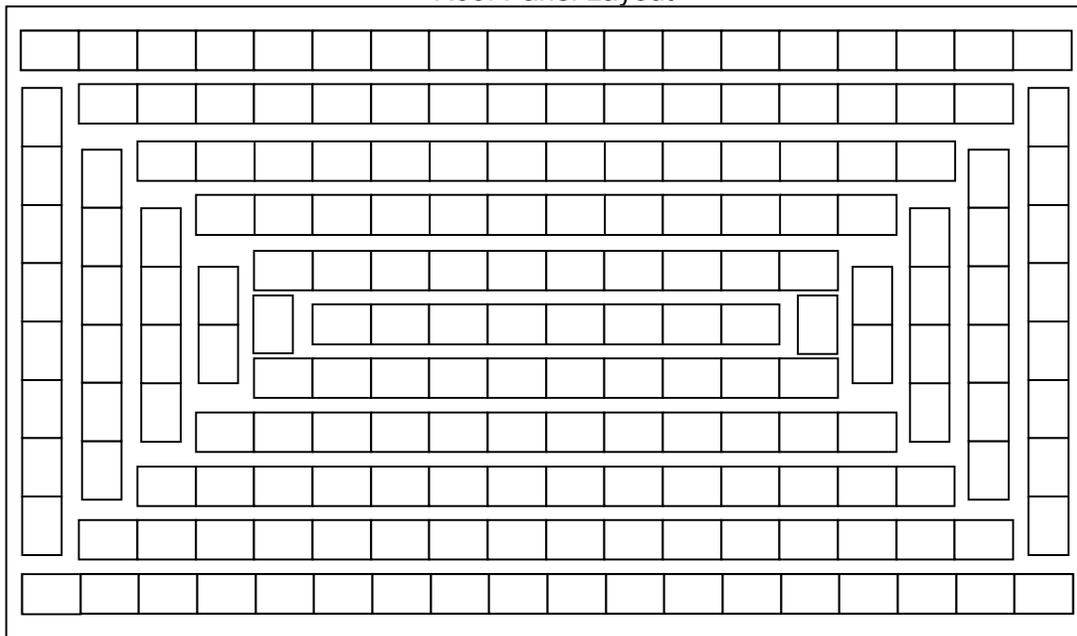
The table only lists roof areas, however, it can be assumed that building facades do offer at least 3 times the space of the roof areas. Those vertical areas could also be used to utilize PV modules.

#### Available Roof Surface Area for Installation of Panels

Building	Total Roof Area Square Feet	Usable Area	Solar Panels fitting into Area	Total Inst. KW	Predicted kWh during summer
Elevated Station	31562	26828	1916	335.35	496422
Cryo Lab	3000	2550	182	31.88	47185
WW#3	672	571	41	7.14	10570
AFM	192	163	12	2.04	3020
RF Building	759	266	19	3.32	4916
TDRSS SPTR 2 Conex	156.8	133	10	1.67	2466
VFM	160	136	10	1.70	2517
DSL/Bicep Building+Walkway	2260	904	65	11.30	16728
Mapo	1104	442	32	5.52	8171
Astro	1194	597	43	7.46	11047
Ice Cube Drill Lab	1104	662	47	8.28	12257
ARO	1104	662	47	8.28	12257
Cargo - 3 Bldgs near Hypertats	1680	1008	72	12.60	18652
Alti Meadows	1800	1350	96	16.88	24981
Weight Room (Summer Camp)	336	286	20	3.57	5285
Mechanical Rooms of Summer Camp	336	286	20	3.57	5285
Total	36185	30378	2170	379.72	681757

For the roof areas it is assumed that the PV modules are installed in an 80 DEG angle to the horizontal. They are installed in rows, each row facing a different direction. The rows are staged to each side of the building to make use of the very low sun angles.

Roof Panel Layout



In order to compare the harvested solar energy with the fuel needed for the production of electricity, the following relations were used.

**Fuel Oil**

\$ per Gal Fuel	30
kWh per Gal API	13.04

The table below shows the possible fuel savings assuming that all available roof areas are equipped with PV modules. The Elevated Station alone would provide 73% of the calculated fuel savings. Assuming installation only on horizontal areas, 52,282 Gal could be saved annually. That equals 12.3% of the fuel needed or \$1,568,460.

**Potential Savings**

Total Predicted kWh during summer	Gal Fuel used for FY 08 power prod.	Total Seasonal kWh produced by plant generators	Gal of Fuel saved by Solar Panels	% of Fuel saved by solar panels
681757.4	426725	5564495	52282	12.3%

This can also be expressed in the following ratio:

**Fuel Savings Ratio**

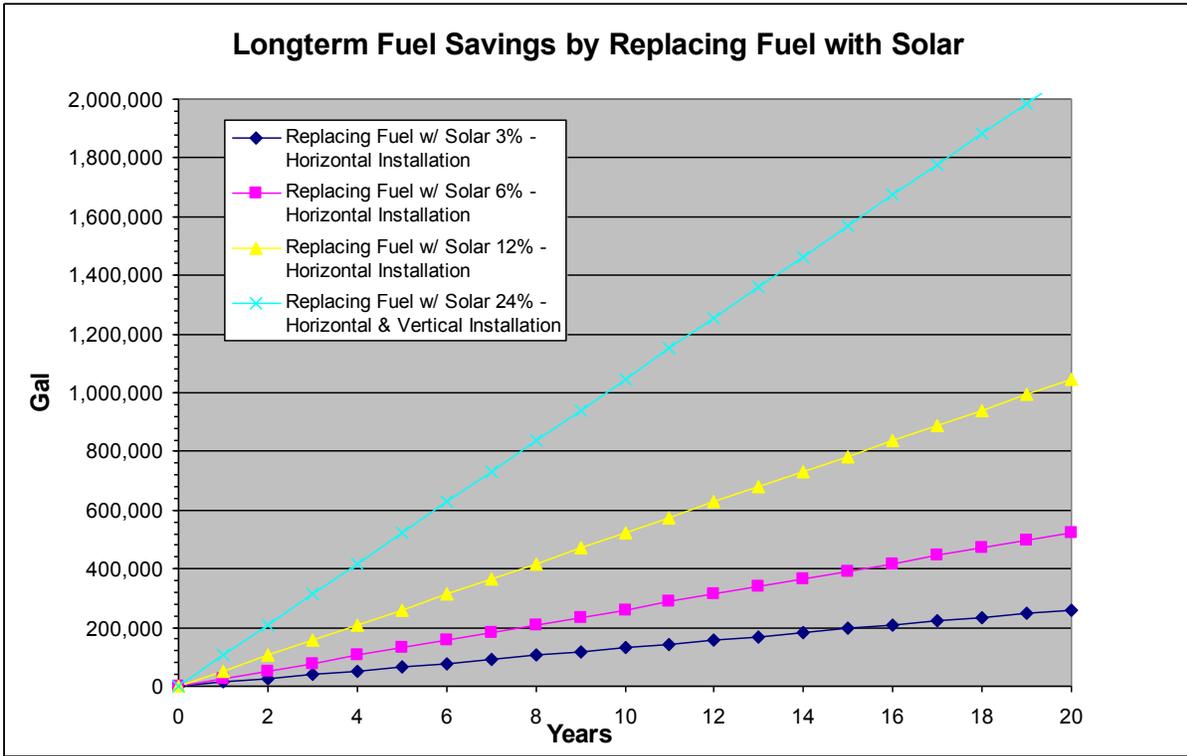
Gal Fuel saved annually per 100 solar panels		2409
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Given the cost for the solar system (only material cost), payback periods of less than 2 years are possible. The table below also considers the possibility of using horizontal and vertical areas. The 25% fuel saving option assumes that there is an equal area of vertical space that is added to the already calculated horizontal space. Since the available vertical areas are at least 3 times the space of the horizontal areas, even greater savings might be possible.

**Payback**

Replacing Fuel with SolarPower	Cost of SolarPower System	Annually Saved Fuel Cost at 30\$/Gal	Payback Period Years	Installation Type
25%	\$5,316,106	\$3,136,920	1.69	Horiz+Vertical
12.3%	\$2,658,053	\$1,568,460	1.69	Horizontal
6.1%	\$1,329,027	\$784,230	1.69	Horizontal
3.1%	\$66,513	\$392,115	1.69	Horizontal

The following graph shows the expected fuel savings for various fuel replacement goals. Over 20 years, fuel savings could reach from 220,000 Gal to more than 2,000,000 Gal.



This last graph shows the expected savings for various fuel replacement goals. Over 20 years dollar savings could reach from \$7,000,000 to more than \$60,000,000.

