SPARTAN SUPERWAY

Solar Energy Analysis

Introduction

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Background

Sustainable Mobility System for Silicon Valley (SMSSV), otherwise known as Spartan Superway, is an interdisciplinary project from San Jose State University to design a PRT (Personal Rapid Transport) system using renewable resources

The objective of the Spartan Superway is to address the following transportation issues:

- Traffic congestion
- Loss of productivity from time spent in commuting and/or parking
- Continued use of and dependence on hydrocarbon fuels
- Increased possibility of accidents that injure people and damage property
- Environmental degradation from greenhouse gas emissions and by products from wear out of parts

Solar Analysis Objectives

- Provide analysis on the power collection capabilities
- Determine the mounting angle that will provide maximum annual energy output
- Determine the number of solar panels per length of track required
- Determine power and energy requirements for a battery system

For this analysis the following assumptions were considered:

Nominal Speed= 50 Miles/hr

Acceleration= 0.5g

Vehicle weight including passengers=1900 Kg

Methodology

PVWatts was used to determine the optimal tilt angle

Force and energy calculations were used to determine the number of solar panels required to operate at constant speed

Acceleration energy and max power output was calculated to determine battery requirements

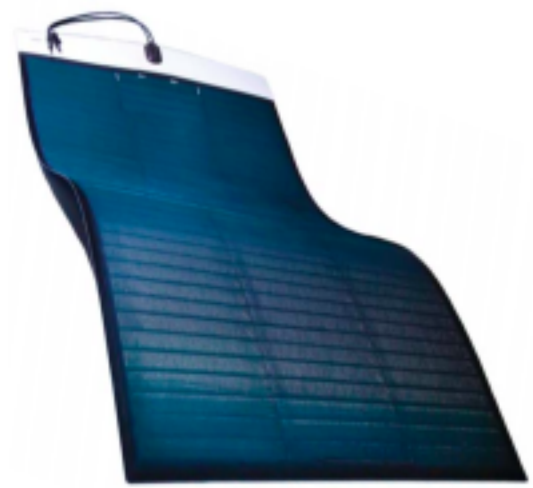
A “2 to 1 spacing ratio” was used to determine the maximum number of panels that can be positioned along the track

Solar Panel Specs

Type: FLEX -02 340 W

			FLEX–02 340W	FLEX–02 350W	FLEX–02 360W	FLEX–02 370W
Nominal Power	P_{MPP}	[W]	340	350	360	370
Aperature Efficiency	η	[%]	14.8%	15.3%	15.7%	16.1%
Power Output Tolerance		[W]	+10/-0	+10/-0	+10/-0	+10/-0
Maximum Power Voltage	V_{MPP}	[V]	30.5	31.0	31.6	32.2
Maximum Power Current	I_{MPP}	[A]	11.23	11.33	11.43	11.52
Open Circuit Voltage	V_{OC}	[V]	38.3	38.8	39.3	39.8
Short Circuit Current	I_{SC}	[A]	12.97	12.99	13.02	13.04
Maximum Series Fuse Rating		[A]	25			
Maximum System Voltage	(IEC/UL)	[V]	1000/600			

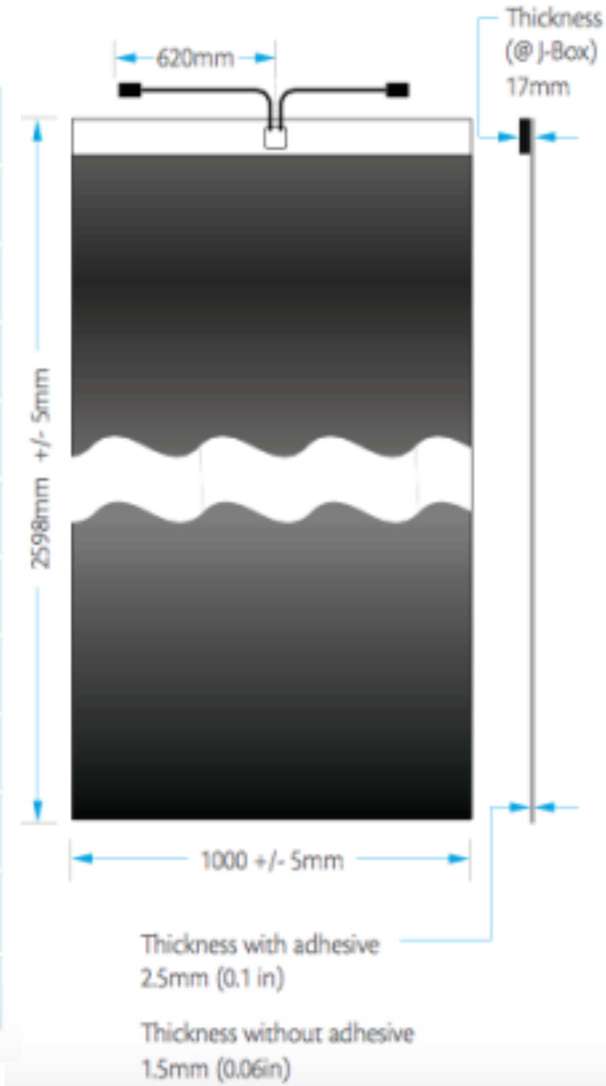
[1]Standard Test Conditions (STC): 1000 W/m², 25°C cell temperature, AM 1.5 spectrum



Solar Panel Specs Cont'd

PHYSICAL AND MECHANICAL SPECIFICATIONS

Length	2598 mm (102.3 in)
Width	1000 mm (39.4 in)
Thickness, Maximum at J-Box*, Module	17 mm (0.7 in), 2.5mm (.1 in)
Weight (Module without adhesive)	5.1 kg (11.1 lb)
Weight (Module with adhesive)	6.2 kg (13.7 lb)
Weight/Area (Module without adhesive)	2.0 kg/m² (0.4lb/ft²)
Weight/Area (Module with adhesive)	2.4 kg/m² (0.5lb/ft²)
Junction Box Type	IP68
Cable Connections	Amphenol H_4
Cell Type	Copper Indium Gallium Diselenide (CIGS)
Warranty**	5 year workmanship; 10/25 year power output
Certifications	UL 1703, IEC 61646, IEC 61730

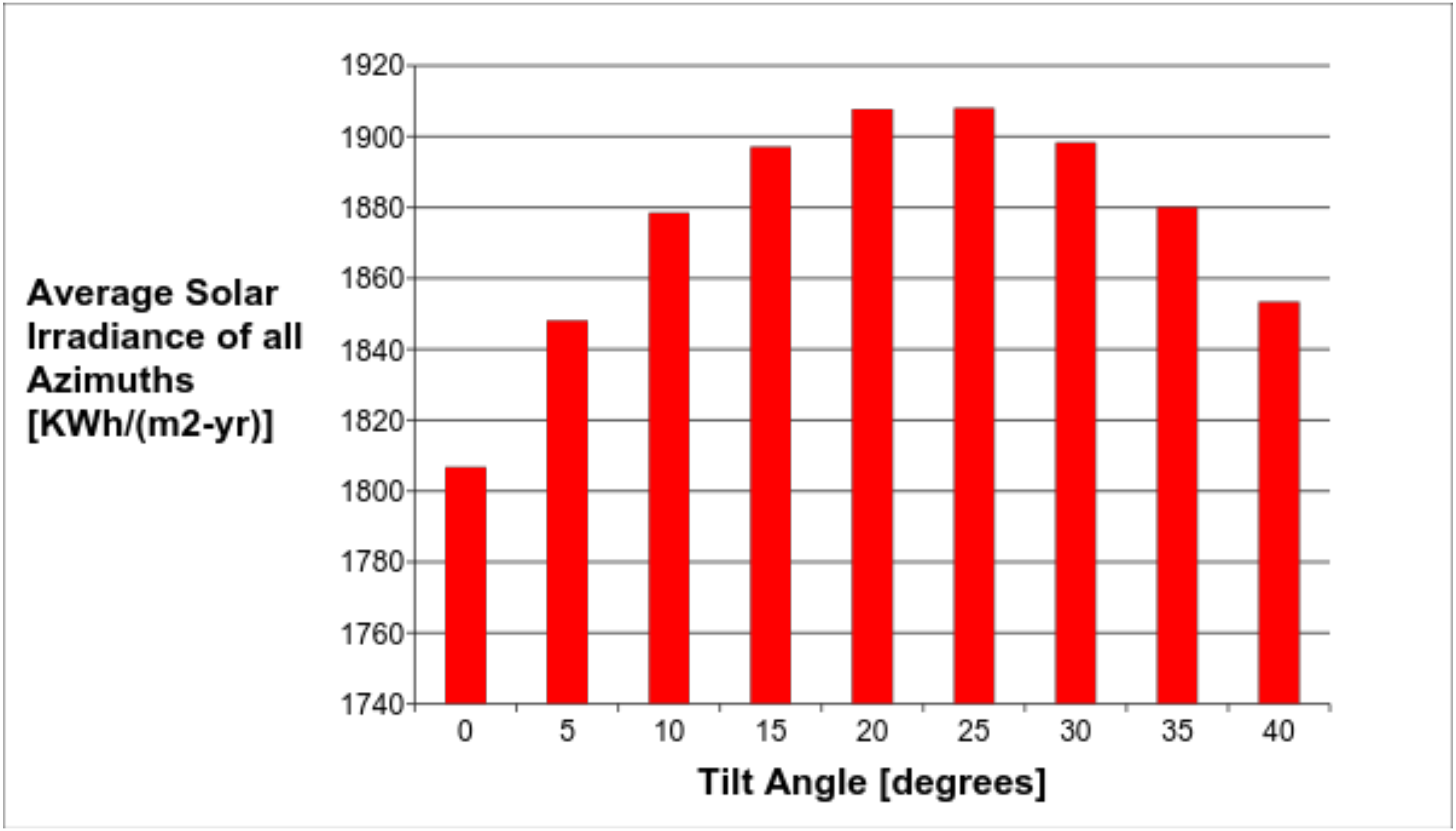


PVWatts Positioning Analysis

	Azimuth									
	W	SWW	SW	SSW	S	SSE	SE	SEE	E	H_bar Average
Tilt	270	247.5	225	202.5	180	157.5	135	112.5	90	kWh/(m^2-day)
0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	4.95
5	5.0	5.0	5.1	5.1	5.2	5.1	5.1	5.0	4.9	5.06
10	5.0	5.1	5.2	5.3	5.3	5.3	5.2	5.1	4.9	5.15
15	4.9	5.1	5.3	5.4	5.5	5.4	5.3	5.1	4.8	5.20
20	4.9	5.1	5.4	5.5	5.6	5.5	5.3	5.1	4.8	5.23
25	4.8	5.1	5.4	5.6	5.2	5.5	5.3	5.0	4.7	5.18
30	4.7	5.1	5.4	5.6	5.6	5.5	5.3	5.0	4.6	5.20
35	4.6	5.0	5.4	5.6	5.6	5.5	5.3	4.9	4.5	5.15

The above chart was composed using the PVWatts tool at PVWatts.NREL.gov. The website uses TMY3 data to calculate direct, diffuse and ground irradiance and outputs the daily output averaged over the period of one year. By inputting an array of azimuth and tilt angles it was possible to determine which azimuth and tilt generates the most energy over the period of one year.

Optimal Tilt Angle (TMY3)



Vehicle Energy Requirements – Rolling Resistance

The *rolling resistance* can be expressed as

$F_r = c\ W/r$

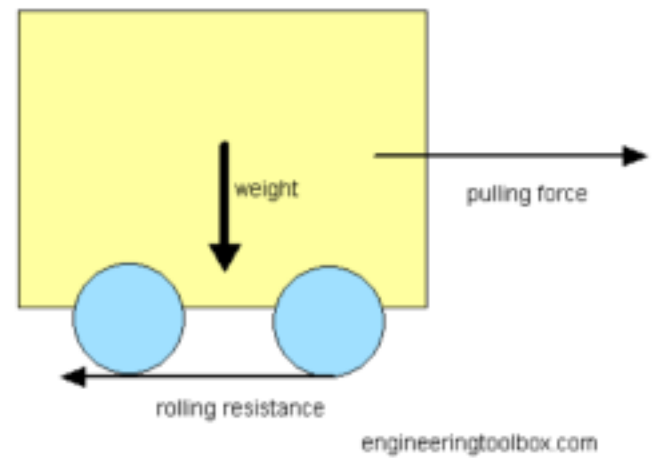
where

F_r = *rolling resistance or rolling friction*

W = *weight of the body*

c_l = *rolling resistance coefficient with dimension length*

r = *radius of wheel*



Constants used	
# of wheels	4
Cl [m]	3.00E-04
Mass w/ passengers[kg]	1900
radius [in]	6

Result	
Fr [N]	147

Vehicle Energy Requirements – Drag Force

Drag force can be expressed as:

$F_d = \mu\ 1/2\ \rho\ U^2\ A$

where

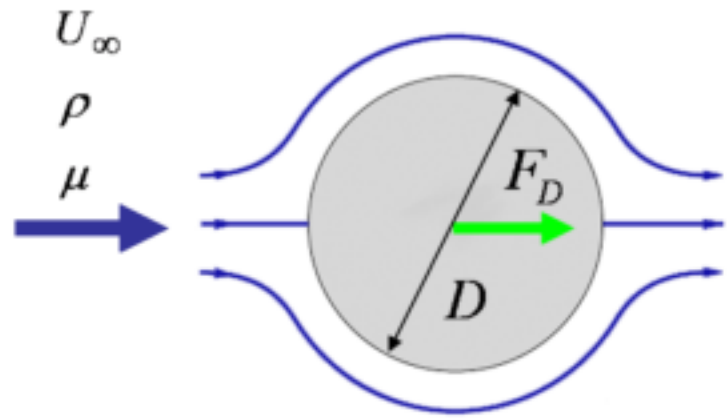
F_d = *drag force*

μ = *drag coefficient*

ρ = *density of fluid*

U = *flow velocity*

A = *characteristic frontal area of the body*



Constant Values Used	
Drag Coefficient	0.3
Height [m]	2.24
width [m]	1.9
Air density [kg/m^3]	1.225

Single Cabin Results	
V [mph]	Fd [N]
5	2.5
10	9.9
20	40
30	89
40	159
50	248

System Solar Panel Requirements

V [mph]	Time to move 1km (s)	Energy Produced per Panel (J)	Total Energy Required (J)	Total Power Required (W)	# of panels needed per km to operate 5.5 hrs per day
5	447	152021	149242	334	1
10	224	76010	156679	701	3
20	112	38005	186423	1668	5
30	75	25337	235997	3167	10
40	56	19003	305401	5464	17
50	45	15202	394634	8826	26

The number of solar panels required to move the cabin was calculated using the following three step process:

1. Calculate the time required to move the cabin 1 km at the given velocity
2. Calculate the amount of energy produced by a single panel in that amount of time
3. Using the amount of energy required, the time available and the amount of energy produced by a single panel, calculate the number of panels required

Vehicle Energy Requirements – Acceleration Force

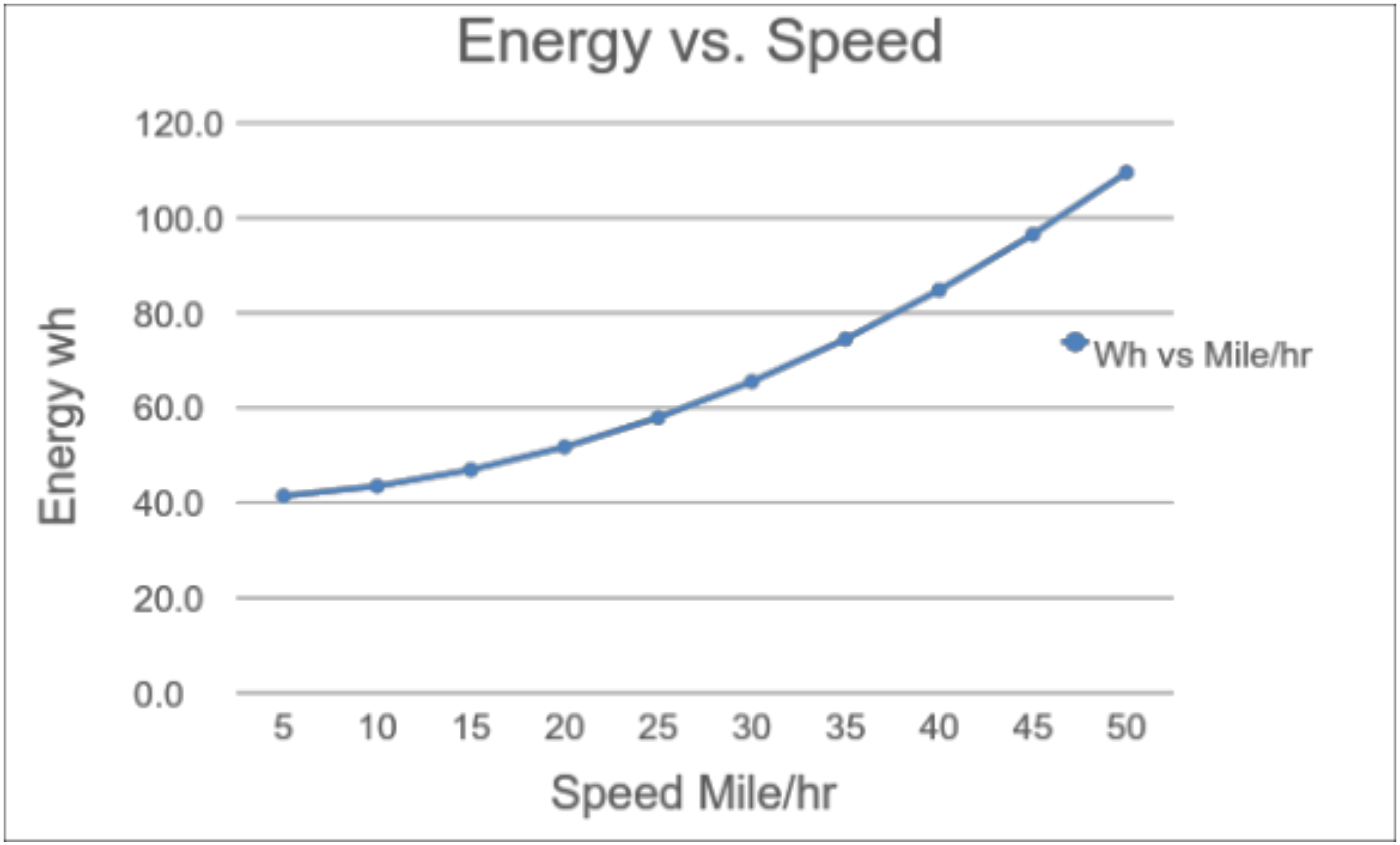
acceleration (m/s2)	4.905

total drag force energy (J)	6180
total rolling resistance energy (J)	7289
total acceleration energy (J)	462835

total energy during acceleration to 50 mph (J)	476304
max power dissipated during acceleration to 50 mph (kW)	212
max power dissipated during acceleration to 50 mph (hp)	284

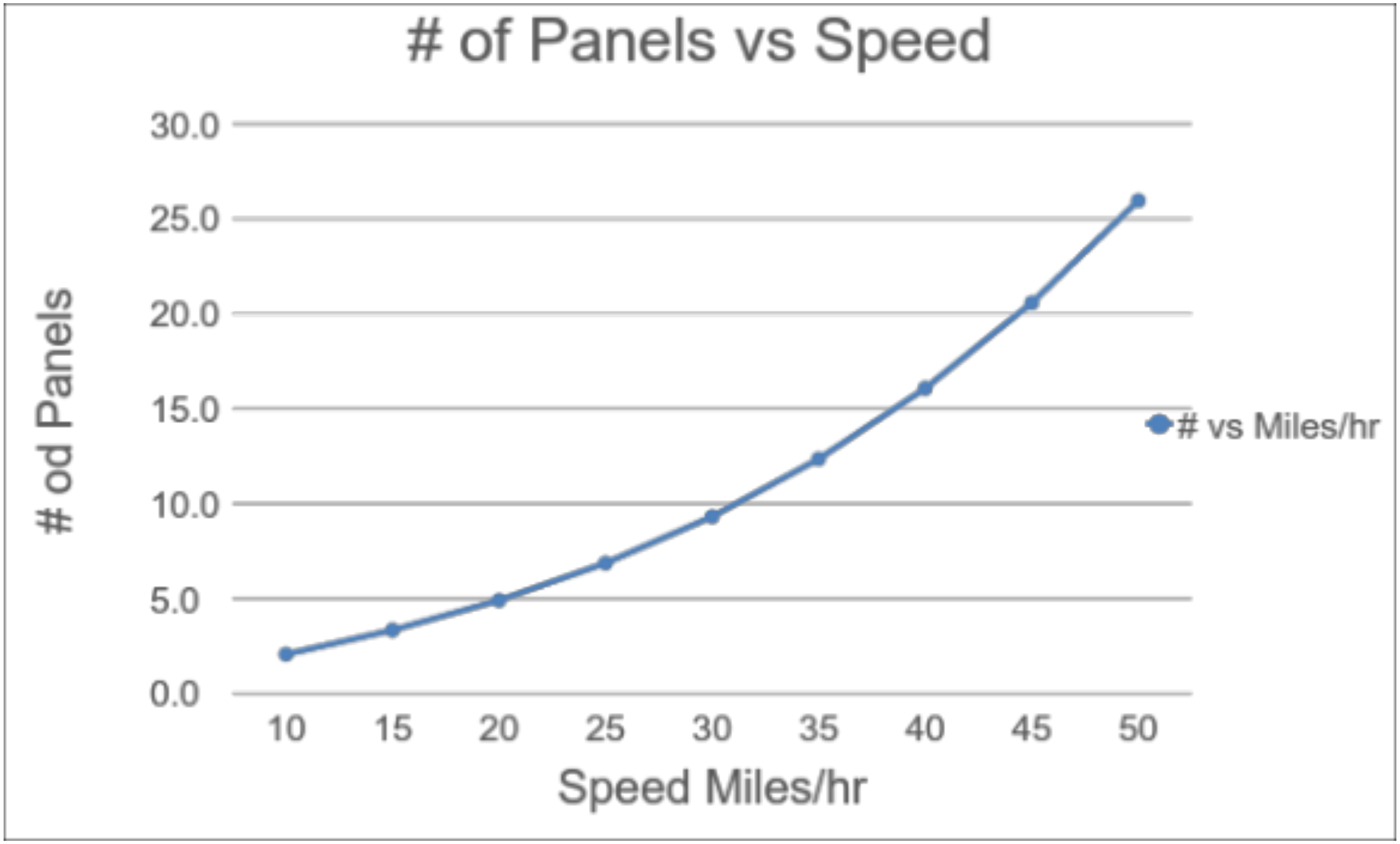
- The amount of energy required during an acceleration of 0.5g up to 50 mph was calculated by discretizing time and calculating the energies required to overcome drag force, rolling resistance and inertial forces for each incremental time step.
- From this calculation we can determine the energy and power output required for a battery that would be used to provide power to the vehicle during acceleration .

Results



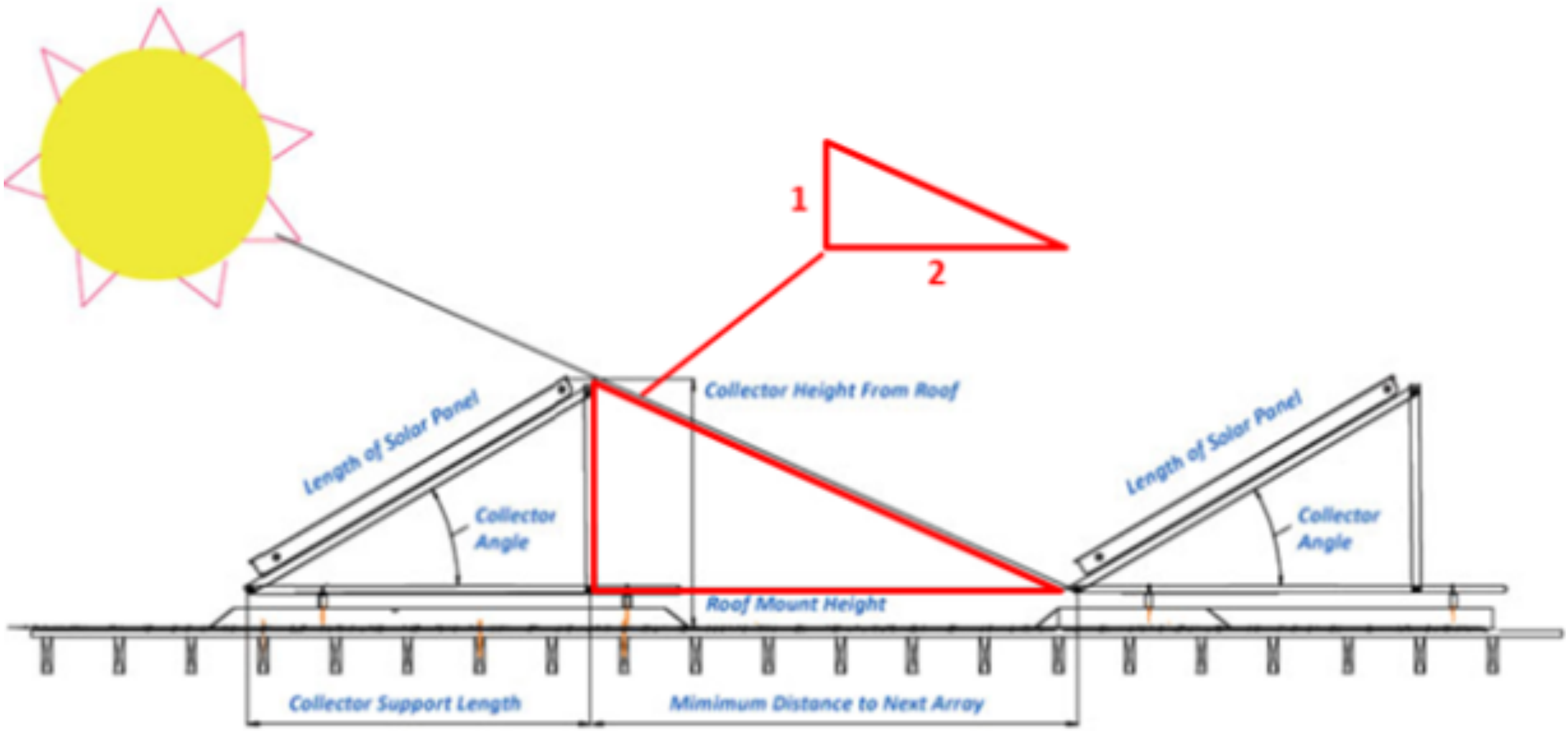
The above graph shows the amount of energy required to move the vehicle at constant velocity

Results



The above graph shows the number of panels required to move the vehicle at constant velocity

Total Energy Capability



Using a 2 to 1 spacing to height ratio, the maximum number of panels that can be included in a 1 km length is 1,234 panels. This number of panels can produce 2,308 kWh of DC energy per day on average.

Conclusion

- The best azimuth for year round energy production considering all azimuths in San Jose is 20 degrees
- Given the current dimensions, weight and rollers on the vehicle, a total of 8.8 KW are required to move each vehicle at 50 mph. At peak sun output, it would require 26 panels to achieve this power which means that for every 5.5 hours of desired operation per day 26 panels would need to be placed per km, not considering acceleration energy requirements
- The maximum power output required by a battery to accelerate the vehicle up to 50 mph at 0.5g is 212 kW
- The total energy output required for acceleration is 476 kJ (or 0.13 kWh)
- With the current panels selected, and adequate spacing, the maximum energy output capability is 2308 kWh/day

References

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2. http://miasole.com/uploads/media/FLEX-02W_Datasheet_1.pdf
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4. http://pvwatts.nrel.gov/