Solentic Energy

February 20, 2017

Steve Whitmore
School of Engineering Science
Simon Fraser University
Burnaby, British Columbia
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RE: ENSC 405W Functional Specifications – SolarPath™: Multi-sourced Renewable Energy System

Dear Dr. Whitmore,

Attached is a requirements specification document regarding the SolarPath™ renewable energy system from Solentic Energy. Our intentions are to research, design and build a renewable energy tile which will generate electricity through solar and mechanical methods. Both methods will work synchronously in order to charge a connectable battery bank.

The purpose of the requirements specification is to give insight on the overall design of SolarPath™. This overview includes both the intended requirements and the design of the system – which includes the proof of concept, alpha prototype, beta prototype and production gamma prototype. This document will be used by our team as a reference during the research, design, development and construction of SolarPath™.

Solentic Energy is comprised of five passionate engineering science students: Destiny Hsu, Imran Kanji, Klein Gomes, Nolan Magee and Jin Xiong. If you should have any questions or concerns relating to our requirements specification, please do not hesitate to email our principle contact, Klein Gomes, at kleing@sfu.ca.

Sincerely,

Destiny Hsu
CEO
Solentic Energy

SolarPath™

by

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Submitted to: Prof. Steve Whitmore – ENSC 405w
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ABSTRACT

The price of solar is now cheaper than burning fossil fuels in many world markets, with economists predicting costs lower than fossil fuels across all world markets by 2024 [1]. Solar energy is cheap, plentiful, and most importantly, it is renewable. With the effects of climate change being more pronounced as our dependence on fossil fuels increases, it is now paramount that we find alternative solutions to our energy demands.

Solentic Energy's SolarPath™ is part of the solution. Combining both solar cells and kinetic motion to provide energy to nearby buildings and to help reduce our dependence on fossil fuels. By harnessing multiple methods of energy generation, SolarPath™ can produce more energy throughout the day, even if the sun's not shining. This gives SolarPath™ a unique advantage over competitive products – some of which only generate electricity using a single method.

SolarPath™ uses kinetic energy as a complementary method of generating energy. The primary area of installation would be busy sidewalks and pathways. Sidewalks located in sunny high traffic areas such as beaches and parks would be ideal since there is adequate sunlight and a large amount of foot traffic throughout the day.

Figure 1: Example of pedestrians using sidewalk and streets in downtown Vancouver [2]

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GLOSSARY

CSA	- Canadian Standards Association
DC	- Direct Current; a DC motor provides a constant voltage
IEEE	- Institution of Electrical and Electronics Engineers
LED	- Light Emitting Diode
PV	- Photovoltaic; describes a product that uses the photovoltaic effect, capturing and converting photon energy (light) into electrical energy (voltage) [3] [4]
RoHS	- Restriction of Hazardous Substances
RPM	- Revolutions Per Minute

1.0 INTRODUCTION

SolarPath™ is an energy generating tile developed by Solentic Energy. It combines both solar energy and kinetic energy from footsteps and stores it in a battery bank. The energy tile is modular and interconnects to other tiles to cover sidewalks and other walkways. The system requirements for the energy tile itself and the connections to a battery bank will be outlined in this document.

The development of SolarPath™ will occur over four phases: Proof of concept, alpha prototype, beta prototype and final production gamma prototype. The proof of concept will be constructed using cheaper materials such as wood and plastics whereas the alpha, beta and gamma prototypes will employ a more rigid metal alloy or composite materials. All phases will include solar cells and a basic vertical kinetic energy generator. The final prototype of SolarPath™ will also comply with CSA and IEEE guidelines.

The targeted completion periods for each stage is as follows:

- Proof of Concept - April 10, 2017
- Alpha Prototype - May 30, 2017
- Beta Prototype - June 30, 2017
- Gamma Prototype - August 8, 2017

1.1 SCOPE

This document will cover the requirements that need to be met in order for the successful completion of Solentic Energy's SolarPath™. Requirements are ordered in terms of priority where the higher priority requirements will be fundamental to the success of the project. Lower priority requirements are to be regarded as a "desirable" feature and may not be essential to the overall goal of SolarPath™.

1.2 INTENDED AUDIENCE

This requirement document is intended to be used by employees of Solentic Energy as a reference in the research and development of SolarPath™. The mechanical and electrical engineers can use this document to refer back to design requirements and safety specifications. The project managers can use this document to view specified timelines, targeted completion dates and overall progress of the SolarPath™ project.

1.3 CLASSIFICATION

In these specifications, the requirements and process details will be classified according to the following convention:

[SR - ## P] <System requirement text>

The letters indicate the section header, ## indicate the requirement number, and **P** is the priority of the requirement, following the following definitions:

A – High: necessary for basic product functions, requirement must be met for proof-of-concept prototype. Also known as hard goals; absolutely mandatory to meet said requirements.

B – Medium: desirable features, implementation dependent on results of alpha and beta testing, time and budget constraints dictating feasibility. Also known as soft goals; performance close to said requirement will be deemed acceptable.

C – Low: non-mandatory refinements and additional functions/features that would be implemented in a final product if given enough time. Also known as optional goals; completion or non-completion will not affect final product.

For example, **[SR - 3 B]** would indicate the third system requirement or soft goal that would be desirable for the final product.

2.0 SYSTEM OVERVIEW

2.1 USE CASE

The user of the SolarPath™ will be any pedestrian passing along the surface of our product. While primary users are pedestrians, which include adults or children walking or running by, additional use cases also include wheeled transportation, such as wheelchairs, scooters, or cyclists.

2.2 TOP LEVEL DESIGN

SolarPath™ consists of two integrated subsystems to simultaneously provide a walking surface for pedestrians and energy generation. These two subsystems include one that captures solar energy and another that captures the kinetic energy from pedestrians' footsteps. The walkable surfaces of individual tiles will be seamlessly linked together and provide charge for an external battery source.

The following two figures conceptualize how the completed design will appear from the bottom and side-profile perspectives, respectively. Visible are fundamental components from both the solar and kinetic energy subsystems; the transparent protective surface, the solar panel, springs and generator, magnetic connectors, and the component housing.

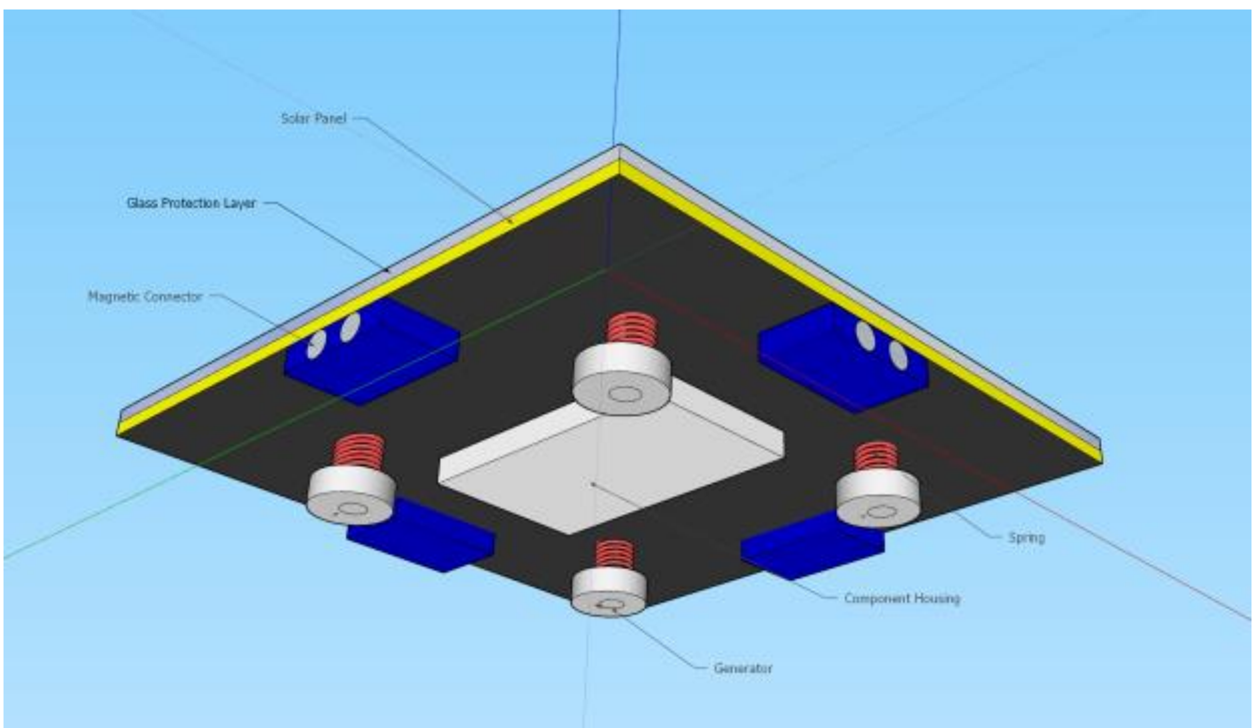


Figure 2: SolarPath™ concept design, bottom view detailing kinetic systems and interconnects

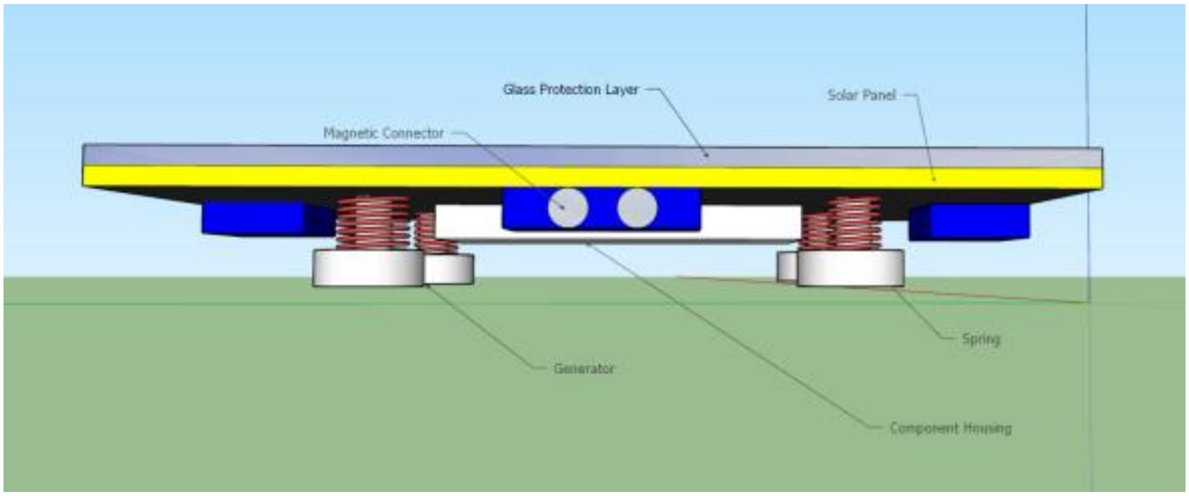


Figure 3: SolarPath™ concept design, side view detailing solar subsystem layers, support springs and generators

The following figures demonstrate the solar energy and kinetic energy harnessing subsystems, respectively. The two subsystems will be both installed into each tile module, working in parallel and independently of one another to charge the same external source.

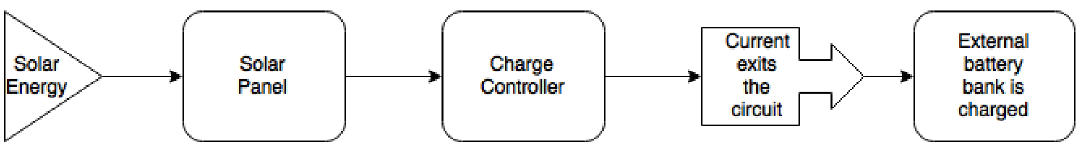


Figure 4: Solar Subsystem flow chart, showing the progression of solar power through the system into external source

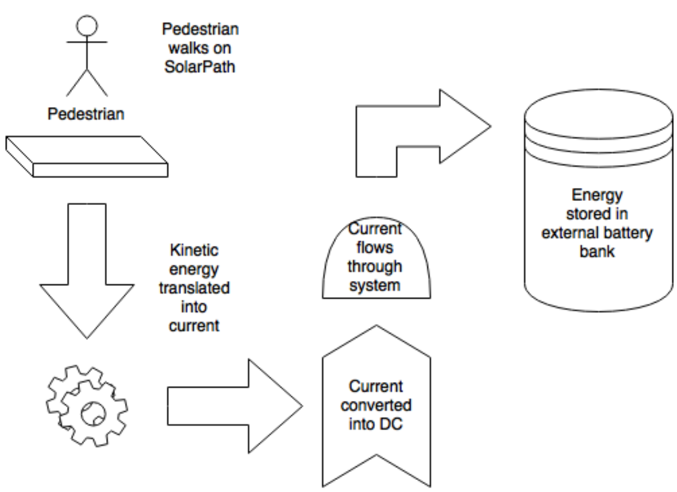


Figure 5: Kinetic Subsystem flow chart, showing progression of pedestrian input through system to external source

2.3 PROTOTYPES

Our development process will include four prototypes: Proof-of-Concept, Alpha, Beta, and Gamma. The Proof-of-Concept will be constructed from wood, and serves the function of validating the design of our solar and kinetic energy capturing systems. The Alpha and Beta prototypes will evolve by including a metal chassis and more refined materials and circuits, and will continue the evolution towards our final prototype. The Gamma prototype will be our final version and will have full functionality, including a complete weather-resistant enclosure, interconnectability between tiles, and an outlet to charge the external battery bank.

The targeted completion period for each stage is as follows:

- Proof-of-Concept - April 10, 2017
- Alpha Prototype - May 30, 2017
- Beta Prototype - June 30, 2017
- Gamma Prototype - August 8, 2017

3.0 SYSTEM REQUIREMENTS

3.1 FUNCTIONALITY JUSTIFICATION

The functionality was determined by realizing that the energy from footsteps is largely unharnessed in society, even with the available technology and products available. Of concern was allocating a large amount of real estate to a technology with a low amount of energy generated, and this led to a clear solution of incorporating solar panels, which are a growing source of sustainable energy and will make use of the space required.

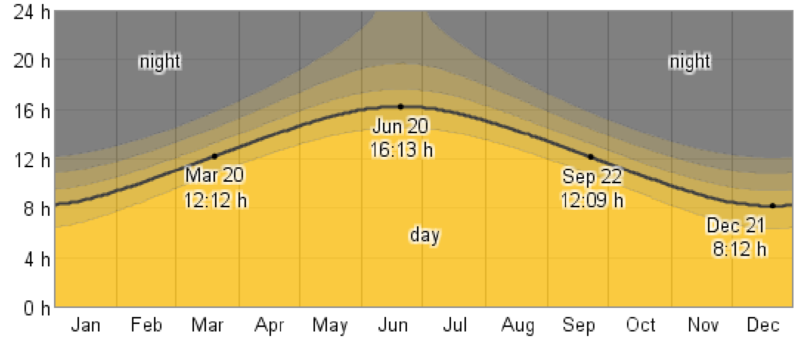
This section describes the operating conditions that the product will be designed to withstand. The product will operate under all weather conditions, and will therefore be subject to temperature extremes as well as rain and snow. Pedestrian traffic means the product will require a high weight capacity. SolarPath's™ weather resistant enclosure will allow the product to provide energy in various conditions and increase its product life and the sustainability of harnessed energy.

The physical enclosures of the modules will be given a minimalist approach with no visible circuitry. In the final version, the enclosure will be waterproof and constructed for long-term use. SolarPath™ will also require a durable scratch-resistant surface to allow light to pass through and be absorbed by the solar panel, but also to support the weight of pedestrians in lieu of a sidewalk or pathway.

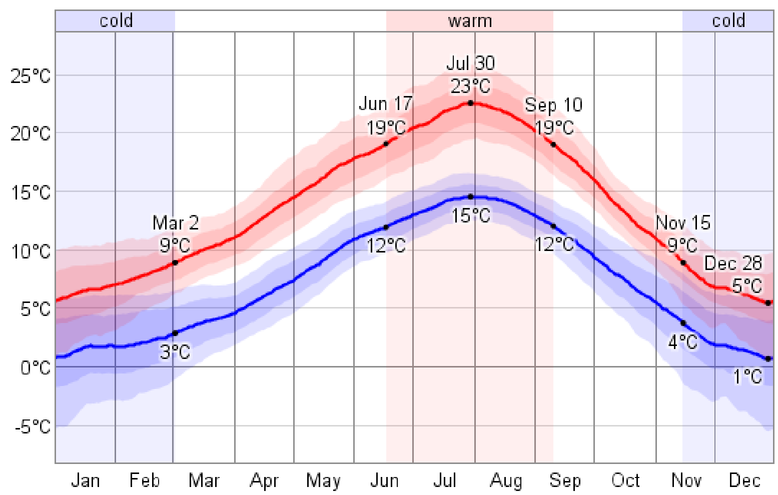
3.1.1 OPERATIONAL CONDITION ESTIMATES AND CALCULATIONS

In order to justify the operating ranges and parameters of the system, we have taken into account the intended use of the product as an outdoor, all-weather walkway, in addition to the projected efficiency of our solar subsystem.

Solar panel efficiency is affected by the panel's "temperature coefficient", which determine the power loss for every 1°C rise of temperature above 25°C. [5] This relationship is a linear one; for example, most monocrystalline solar cells have a temperature coefficient of -0.5%/°C, indicating that a panel created from these cells will lose 0.5% power efficiency for every degree of temperature increase beyond 25°C. [6] [7] [8] Ideally, a solar panel would operate at a maximum of 25°C, however, under direct sunlight panel can rise up to 50°C above ambient temperatures. [9] In Vancouver, British Columbia, the average daily hours of sunlight over the course of a year are given in Graph 1, while the corresponding high and low temperatures are shown in Graph 2;



Graph 1: Daily hours of daylight and twilight in Vancouver, BC, based on records from 1977-2012 [10]



Graph 2: Daily high and low temperatures in Vancouver, BC, based on records from 1977-2012 [10]

Based on these values, we project a minimum operating temperature of -10°C, several degrees below the observed minimum, and a maximum of 80°C, which is well over 50°C above the observed maximum.

With SolarPath's^{TM} use as a kinetic generator and pedestrian walkway, the product will be expected to perform under high physical duress as well. The intended use of the product will be as a sidewalk in high-traffic areas, which restricts the size to approximately 12 cm x 60 cm x 60 cm (1"x2"x2") to fit in a standard sidewalk tile. [11] Each tile must also withstand not only the weight of pedestrians, but bear loads such as wheelchairs, strollers and bicycles, therefore we have set a goal of 181 kg (400 lb) for our product's weight capacity.

Regarding the long-term usage of our product, a typical solar panel's lifespan is between 20 to 25 years. [12] However, due to the kinetic motor subsystem, our product's lifespan will be capped by the lifespan of the moving parts. Table 1 below shows the total number of pedestrians on a typical day (from 10am-6pm) on the busiest Vancouver blocks;

Table 1: Total number of pedestrians during peak hours (10am-6pm) on busiest Vancouver blocks [13]

Block Rank	Total Pedestrians (10am-6pm)	Block
1	25,042	Granville, S of Georgia (700 block)
2	18,689	Granville, S of Pender (500 block)
3	17,960	Georgia, E of Howe (700W block)
4	17,354	Granville, S of Dunsmuir (600 block)
5	17,266	Burrard, S of Georgia (700 block)
6	17,238	Robson, E of Seymour (500 block)
7	16,812	Granville, S of Robson (800 block)
8	16,651	Burrard, S of Melville (600 block)
9	16,544	Georgia, E of Hornby (800W block)
10	16,468	Robson, E of Burrard (900 block)

This heavy usage will wear down the moving components as well as the walking surface. In order to try and maximize the solar panel use and minimize costs and wastes for part replacements and repairs, we have projected a product lifespan of ten years. During the product's operational lifespan, the kinetic motor subsystem can be serviced and replaced as required, while at the end of the lifespan the solar subsystem can either be extracted for reuse in a new SolarPath™ module or recycled.

Based on our findings, our operational conditions for our product are tabulated below;

Table 2: Values for operational ranges and physical properties of system

Operational Temperature:	-10°C to 80°C (14°F to 176°F)
Weight Capacity:	181 kg (400 lb)
Estimated Life Cycle:	Approx. 10 years
Dimensions:	Approx. 12 cm x 60 cm x 60 cm (1"x2"x2")

3.2 GENERAL REQUIREMENTS

[SR - 1 A] The product will generate DC voltage output from both solar cells and kinetic motors for an external battery bank

[SR - 2 A] Each complete product module will be contained in a tile structure, housing both the solar and kinetic subsystems

[SR - 3 A] Each module must have an outlet for DC output to an external battery bank

[SR - 4 A] Each module must have an interconnecting panel to physically and electrically link with other tiles along each side of the unit

[SR - 5 A] The product must be able to be installed securely into the ground over lifespan of use

[SR - 6 C] The product will include an LED Light indicating the module is active

3.3 OPERATIONAL CONDITION REQUIREMENTS

[SR - 7 B] Operational Temperature: the product will operate between -10°C to 80°C (14°F to 176°F)
[SR - 8 A] Weight Capacity: each module must support up to 181 kg (400 lb)
[SR - 9 B] Weather Conditions: the product must operate under any weather conditions, including heavy sun, rain and snow
[SR - 10 B] Estimated Lifespan: the product's proposed lifespan will be a maximum of ten years

3.4 PHYSICAL REQUIREMENTS

[SR - 11 A] The product must have a transparent surface to allow light to reach solar cells
[SR - 12 B] Each module's dimensions must be no greater than 12cm x 60cm x60cm (1"x2"x2") to fit within a standard sidewalk tile [11]
[SR - 13 B] The product must allow compression of no more than 2cm for balance concerns
[SR - 14 A] The product must have a minimum of four support springs, one in each corner, to support top surface of platform and prevent crushing of circuitry and components
[SR - 15 B] The product's support springs must meet the weight capacity requirement [SR - 8 A] and the compression restriction [SR - 13 B]
[SR - 16 B] The product's metal components must be rust-resistant and non-corrosive
[SR - 17 B] The physical interconnections between modules must keep tiles securely interlocked
[SR - 18 A] The physical interconnections between modules must not interfere with compression
[SR - 19 B] The bottom of the product must be completely waterproof and allow product to be placed directly against the ground

3.5 SAFETY REQUIREMENTS

[SR - 20 A] The product must have no exposed wiring or circuitry
[SR - 21 B] Each module's enclosure must shield all internal electrical and hardware components from rainwater and snow
[SR - 22 B] The product's walking surface must be scratch and shatter resistant
[SR - 23 A] The product's walking surface must have slip resistance for pedestrian balance
[SR - 24 C] The product must be easily repairable and serviceable on-site after installation

3.6 ENVIRONMENTAL REQUIREMENTS

[SR - 25 A] The product must be manufactured with RoHS compliant materials [14]
[SR - 26 B] The product's electrical subsystems must be constructed with lead-free and non-corrosive components and solder
[SR - 27 C] The product should be constructed with recycled materials which are also recyclable upon reaching the end of lifecycle

4.0 PROCESS DETAILS

4.1 POWER ESTIMATIONS

4.1.1 SOLAR SUBSYSTEM

A solar panel's energy output is calculated by; [15]

$$E = A * r * H * PR$$

where;

- E = Energy (kw/day)
- A= Total solar panel area
- r =Solar panel yield or efficiency (%)
- H = Annual average solar radiation on tilted panels (shadings not included)
- PR = Performance ratio, coefficient for losses

For a 1 m^2 solar panel, 15.6% efficiency and performance ration 0.7;

$$E = A*r*H*PR = 1 * 15.6\% * 5.17(kw/m^2/day) *0.7= \mathbf{0.56\ kW/day}$$

The exact value will vary depending on the season of the year due to amount of sunlight available.

4.1.2 KINETIC MOTOR SUBSYSTEM

Our product's kinetic subsystem will be using multiple vertical generator motors installed below the solar panels. When a pedestrian steps on the tile, the force from their step will engage a mechanical linkage that will then rotate a DC motor. This rotation will cause a current to occur, which will then flow through SolarPath's™ circuitry and eventually allow the external battery to charge. An example calculation of the power generated can be seen below, where, based on the mass of 60 kg for an average person and a DC motor of 0.6 RPM, lead to 37 W of power generated;

The angular momentum;

$$\omega = rpm * 2\pi / 60 \text{ seconds} = 0.6*2\pi/60$$

For an average person (weight = 60 kg);

$$P_{out} = \tau * \omega = 60kg*9.8* \omega = 37 W \text{ [16]}$$

As motors are generally only 50-60% efficient, we've taken that our upper limit on power output will be approximately **18.5W** per motor.

4.2 GENERAL REQUIREMENTS

[PD - 28 A] The kinetic motor subsystem will work in parallel with the solar subsystem to both provide charge to the battery bank independently
[PD - 29 A] Connection of the circuits between tiles must be in parallel in order to scale safely when multiple modules are connected in series
[PD - 30 B] The connection point between individual module's circuits must be weatherproof
[PD - 31 A] The peak amount of voltage generated per tile during use must be greater than 12 V in order to charge a standard battery bank

4.3 SOLAR SUBSYSTEM REQUIREMENTS

[PD - 32 B] At an air temperature of 20°C (68°F), the solar cell should generate 560 W per square meter per day [15]
[PD - 33 B] The maximum power should not exceed be more than 280 wp, max power point voltage shouldn't be more than 31.2 V and max power point current shouldn't exceed 9.07 V [17]
[PD - 34 A] The selected solar panel's voltage rating must match the charging circuitry (eg. a 12 V solar panel is used with a 12 V charge controller to charge a 12 V battery bank and a 12 V inverter)

4.4 KINETIC MOTOR SUBSYSTEM REQUIREMENTS

[PD - 35 A] The motors for the kinetic subsystem must be DC motors
[PD - 36 A] The selected motor's voltage rating must match the charging circuitry (eg. a 12 V motor is used with a 12 V charge controller to charge a 12 V battery bank and a 12 V inverter)
[PD - 37 B] Each motor should generate an upper limit of 18.5W [16]
[PD - 38 B] The motor and components must withstand continuous use and wear of at least 20000 steps per day [13]
[PD - 39 A] Each motor must generate charge in parallel with all other motors in each module

4.5 BATTERY BANK CONNECTION REQUIREMENTS

[PD - 40 A] The connected battery bank must be rechargeable and have a controller
[PD - 41 A] The charging wire output from the product to the battery bank must be 6 gauge [18]
[PD - 42 A] The controller of the battery bank must cut off the charging system when the battery is fully charged to prevent over-charging and shut down the load when not charging to prevent the battery from being drained completely

5.0 ENGINEERING STANDARDS

As a product intended for long-term, outdoor, ground-embedded energy generation, Solarpath™ must be designed to meet various engineering standards pertaining to electrical systems and installations, energy generation systems, and general safety standards.

The product will conform to the following (limited edition) standards;

[ES - 43 A] The product will comply with CSA's C22.1 Canadian Electrical Code sections 1-15 regarding safety standard for electrical installations [19]
[ES - 44 C] The product will allow for repairs and evaluations in the field according to CSA's SPE-1000-13 for field evaluation of electrical equipment [20]
[ES - 45 B] The product will meet the general requirements of CAN/CSA-C22.2 Canadian electrical code, part II, sections 0 -10 [21]
[ES - 46 A] The product's internal circuitry will comply with CAN/CSA-C22.2 Canadian electrical code NO. 0.12-M1985 regarding wiring space and wire bending space in enclosure for equipment rated 750 V or less [22]
[ES - 47 A] The product's solar subsystem will be constructed with PV modules qualified by CAN/CSA-C61215-08 (R2013) [23]
[ES - 48 B] The product will be designed for the environment and sustainability according to the guidelines set by CSA's Z762-95 (R2016) [24]
[ES - 49 B] The product's environmental impact over its life cycle will be assessed according to the guidelines set by CAN/CSA-ISO 14040-06 (R2016) [25]
[ES - 50 C] The product's safe disposal will adhere to the guidelines for managing end-of-life materials as set by CSA's SPE-890-15 [26]
[ES - 51 B] The performance tests for the product's solar subsystem will comply with IEEE standard 1526-2003 [27]
[ES - 52 B] The product will conform to the 1680-2009 - IEEE Standard for Environmental Assessment of Electronic Products [28]
[ES - 53 A] The product will be RoHS compliant according to environmental requirement [SR - 25 A] [14]

6.0 SUSTAINABILITY AND SAFETY

At Solentic Energy, we are dedicated to creating a product which produces a sustainable source of power. Therefore, we also endeavor to work towards making SolarPath™ itself a sustainable and safe device throughout the entirety of its lifespan and beyond.

Our ideal vision for SolarPath's™ lifecycle would be that of the cradle to cradle design, wherein every stage of the product's life would be developed to be as environmentally sound as possible, making use of recycled materials, responsible and renewable manufacturing methods, and be ultimately recyclable with minimal waste. [29] To approach this ideal, we will work through multiple design stages to construct with as many recycled materials as possible, while also developing a sound structure with a long lifespan in order to maximize product use and minimize part replacement.

As stated under [ES - 48,48 B] our requirements for SolarPath™ include following the guidelines for designing for sustainability in Z762-95 as well as life cycle assessment in CAN/CSA-ISO 14040-06, driving our development stages to focus on sustainability. The estimated lifespan for a completed product will be approximately 10 years according to [SR - 10 B], in order to maximize material use and minimize repair costs and waste from over-frequent replacement, as well as being reparable after installation according to [SR - 24 C] and [ES - 44 C]. This will allow for reuse of the solar subsystem between expended modules, and try to minimize waste from motor repairs and replacements. In addition, for the product to be deemed acceptable, we require in [SR - 25 A] for all materials used to be RoHS compliant, allowing long-term use in outdoor conditions without polluting the installation area via harmful or corrosive matter. Finally, the ultimate disposal of SolarPath™ after the end of its lifespan will be compliant to the guidelines outlined in SPE-890-15 from [ES - 50 C], detailing best practices for managing end-of-life materials.

Due to its intended use as a public pedestrian pathway, we demand additional requirements for SolarPath™ to be deemed safe and reliable for all users. By complying with [SR - 7-9,21 B], all of the process detail requirements, as well as the standards for electrical safety outlined by [ES - 1 A], we ensure that our product's electronic components will remain operational and secure under all weather conditions it shall be subject to. In order to assure the safety of pedestrians, we have added in requirements [SR - 12-23 B], which encompass the stipulations that the walking surface be a secure, non-slip and sturdy platform, while also minimizing any risks of losing balance for pedestrians or difficulty in passage for wheelchairs and other wheeled devices on uneven surfaces. As for safety regarding our product's construction, we have requirements [SR - 16 B] and [SR - 24-27 B], which outline the need for materials that will not rust or corrode over long-term, outdoor use, and which are free from hazardous substances that could pollute or cause harm to either users or maintenance workers.

7.0 CONCLUSION

Solentic Energy's SolarPath™ is a product designed to discretely and unobtrusively generate energy from renewable methods. It will be best applied in sunny and high foot traffic areas including sidewalks near beaches, parks and campuses. Harvesting energy from busy sidewalks using solar a kinetic energy can be used to power streetlights stored in batteries or sent straight to the grid. Fossil fuels are a problem since it is an energy source that takes millions of years to produce while nuclear is very expensive and has dangerous by products. We need a green energy and long lasting solution. Novel and renewable energy products like SolarPath™ will help contribute to our much needed green energy future.

This document covered the system overview, system requirements, system sustainability, and safety standards for SolarPath™. The project timelines are also included and partitioned as per each prototype, with a full gamma prototype expected to be completed on or before August 8, 2017.

Our project will consist of four prototypes: proof of concept, alpha, beta and gamma prototypes. Each successive prototype will improve upon build quality by using costlier production ready materials including alloys and glass and more solar cells. The latter prototypes will also implement all design requirements as outlined in this document. Solentic Energy takes safety standards seriously. Each prototype will strictly follow electrical and safety specifications and standards relating to high energy products. User safety is a top priority and will be adhered to with all other core requirements.

The requirements specified in this document are also classified by priority. Higher priority requirements such as ones relating to safety among others, are essential to the successful completion of SolarPath™. While lower priority requirements are seen as "nice to have" which while not essential, will create a more polished final product.

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