UBC Social Ecological Economic Development Studies (SEEDS) Student Report

An Investigation into the Implementation of Pavegen Tiles in the Student Union Building

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APSC 261 – Project Report

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ABSTRACT

The purpose of this report is to provide the details of a feasibility study regarding the installation of Pavegen tiles in the new Student Union Building at UBC. The study was conducted based on a triple bottom line analysis, considering economic, social and environmental factors of the manufacture, transport, installation, service life and disposal of the product. There is limited information available regarding the manufacturing process of the product as this is considered a trade secret, however a reasonable qualitative/comparative analysis was performed. A qualitative description of the emissions associated with transport and disposal is presented, as well as a quantitative cost analysis of the product through its service life. It is difficult to quantitatively analyze the potential social effects of the project, but by utilizing survey data collected from previous SEEDS project reports on similar topics, a justifiable projection was attained. The report concludes with a summary and analysis of the findings in the form of recommendations as to how the project should move forward. Briefly put, we have determined that the current proposal for an installation of Pavegen tiles is not desirable or in line with the goal of sustainability and increased environmental awareness held by the new SUB. Instead, we suggest an alternative implementation scheme using a smaller number of tiles in conjunction with other innovative green technologies in a space we have tentatively dubbed the 'Green Corner.'

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GLOSSARY

- Blast furnace – a furnace used for the extraction of iron from iron ore
- Electric arc furnace – a furnace that uses electric current to melt metal
- Electrolytic solution – a salt solution responsible for the transport of ions
- Greenhouse gas – gases responsible for the re-radiation of thermal energy reflected by the surface of the earth
- Joule – SI unit of energy
- Lithium polymer battery – battery with a lithium anode, a cathode and a solid polymer electrolyte
- Mechanical strain – physical deformation of a material
- Ozone – a triatomic oxygen molecule, poisonous to plants and animals
- Piezoelectric material – material that generates charge when undergoing a mechanical strain
- Polarization – separation of particles into like-charged groups
- Solid polymer electrolyte – a gel responsible for the transport of ions
- Troposphere – the lowest level of the earth's atmosphere
- Vulcanize – chemical treatment of rubber to improve desirable properties (e.g. elasticity, strength, stability)
- Watt – SI unit of power

LIST OF ABBREVIATIONS

- AMS – Alma Mater Society
- GGBS – Ground granulated blast furnace slate
- GHG – Greenhouse gas
- kWh – Kilowatt hour
- LED – Light emitting diode
- Li Po – Lithium polymer
- OPC – Ordinary Portland concrete
- SEEDS – Social ecological economic development studies
- SI – Système International
- SUB – Student union building

1.0 INTRODUCTION TO THE PROJECT

The new SUB is to be a flagship example of the ideals of environmental responsibility held by the students, staff and faculty at UBC. It is also meant to serve as a means for spreading awareness of sustainability-based thinking, emerging 'green' technologies and to allow people to interact with these concepts in a tangible way. The installation of a set of Pavegen tiles has been proposed by Chris Karu, our client, to the UBC Alma Mater Society (AMS) as a way of achieving these goals. The tiles contain a piezoelectric material connected to an LED and a battery for energy storage. When the tile is stepped on, the piezoelectric material is compressed and power is generated. Part of this energy is used to illuminate the LED while the remainder is stored in the battery. This stored energy can later be used to power external devices, such as the energy consumption display board proposed by Mr. Karu.

The Pavegen tiles are a new product, developed approximately two years ago by Laurence Kemball-Cook, an engineering student from Loughborough University in England. The primary purpose of the tiles is to engage students, faculty and staff in a method of alternative energy generation with the results of their actions immediately apparent. Ideally, this participation will serve to alter preconceived notions of energy generation being the province of large scale, dirty, carbon producing processes best left to industrial facilities. It is to communicate a sense of personal empowerment and responsibility for harnessing and directing energy. This report serves as an investigation into the economic, social and environmental impacts that the Pavegen tiles will have on the new SUB and the UBC community at large.

2.0 INTRODUCTION TO PIEZOELECTRIC MATERIALS

Piezoelectric materials are crystalline materials that generate an electrical polarization when an external stress is applied, resulting in a net positive or negative charge on each face of the material.

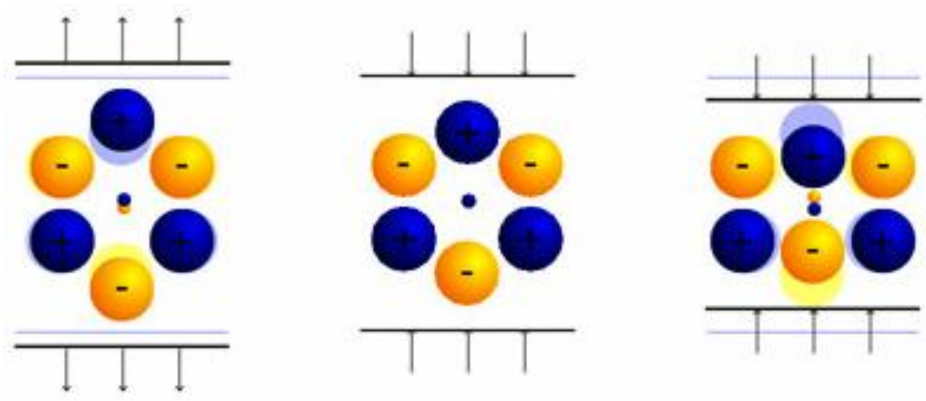


Figure 1: Charge distribution in a piezoelectric material

Source: http://mrsec.wisc.edu/Edetc/SlideShow/contents.html

In general terms, piezoelectric devices generate a voltage when a force is applied, which can be harnessed to generate electricity.

This force can come from many different sources, a human foot, seismic vibrations and even acoustic noise. (Howells, 2008) When a force is exerted on a piezoelectric material, it undergoes a mechanical strain, which creates equal and opposite charges on each face of the material. These charges can drive a current to generate and store power. (Stoeber, 2011)

The voltage generated by a piezoelectric material is calculated as $V = \frac{\Delta l}{d}$ where Δl is the change in thickness of the material due to an external force, V is the voltage generated and d is a property of the piezoelectric material, (generally d is of the magnitude of 10^{-12} and the voltage generated is very large). The amount of charge calculated is equal to $Q = d \times F$ where Q is the charge, d is the same material property mentioned above and F is the force exerted on the material. Again, d is on the order of 10^{-12} which results in a very small amount of charge being generated. To solve this problem, piezoelectric materials are often arranged in stacks such that they generate a more useful amount of charge. (Stoeber, 2011)

3.0 ECONOMIC IMPACT

This section of the report presents a fiscal analysis of the Pavegen tiles based on energy generation capabilities and the initial cost of the product. It concludes with a comparison between the Pavegen tiles and solar panels, another ‘green’ source of energy.

How Much Does It Cost?

Cost per tile, (incl. installation/shipping) = **£**2,500, ($3,850 CAD)

8 tiles = **£**20,000, ($30,800 CAD)

A warranty or guarantee is not issued with the purchase of a Pavegen tile and as a result, the price of the unit over its lifetime could be potentially much higher than $3,850.

Lifetime Energy Generation Value

The rated service life of a Pavegen tile is 20 million steps (Halverson, 2011). Each tile produces 4-8 watts during each cycle (1 footstep) (Pavegen). We will assume an average of 6 Watts for this report. The cost of electricity is 8.85 cents/kWh (BC Hydro, 2011) (UBC taken as a large consumer).

Energy generated: (20millionsteps x 6W/step = 120 million Joules (1 second per step))

120 million Joules x 8 steps = 960 million J

960 million J = 266.67 kWh

266.67 kWh x 8.85cents/kWh= 2360 cents= $23.60

$23.60 = Monetary value of energy generated by 8 units over their lifetime

Cost = $30,800

The energy savings achieved by the Pavegen unit are insignificant. As a result, the net loss over the lifetime of the product is $30,800 – $23.60 = $30,776. The price per watt of a Pavegen tile is extremely high; $642 ($30,800/(8steps x 6W/step)).

Time Period to Offset the Initial Cost of the Pavegen Tiles through Energy Savings

Cost of tiles = $30,800.00

Savings = $23.60 (Every 5 years)

Payback period for 8 tiles = 6525 years

The Pavegen tiles are expensive and produce a negligible amount of power over their lifetime. In terms of energy generation, they are impractical as a primary power source for devices with even modest power requirements.

Comparing Pavegen to Solar Power

The table below shows a comparison of Pavegen tiles and Solar panels. In order to facilitate comparison we have assumed a $30,800 investment in each scenario. For solar panel analysis we assume that the array would produce peak power 4 months per year, operating 10 hours per day. For the remaining 8 months of the year, we assume each panel would generate ¼ peak power, operating for 10 hours each day. For each Pavegen tile we assume a lifetime of 20 million steps.

	Pavegen Tile	Solar Panel
Cost per unit	$3,850	~$600
Total number of units	8	51
Dollars per watt ($/W)	$642	$2
Dollars per joule ($/MJ)	32.08 ($/MJ)	.04550 ($/MJ)

Table 1: Economic comparison between Pavegen tiles and solar panels (assumed 5 year lifetime for each)

(Panel Price, 2011)

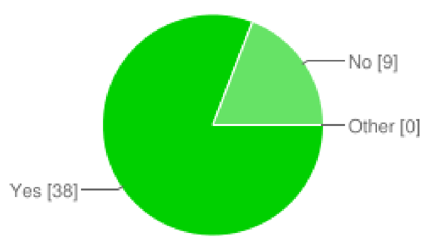
4.0 SOCIAL IMPACT

Performing a social assessment of the Pavegen steps involves an analysis of how students, and the public will view the project, and green technology as a whole.

The "Wow" Factor

The Pavegen step is a new invention, developed by an engineering student in 2009. It's a unique technology with only 1 existing installation at an elementary school in Britain where it is still undergoing testing. Due to the novelty of the step, it produces a "wow" factor that other forms of renewable energy simply don't. "The steps are a great way to give students a visual representation of how they can harvest energy. It just looks good", says Dr. Matthew Baxter, headmaster of the school where the steps are installed. Turning our attention to UBC, we investigated whether people here would be interested or inspired by Pavegen steps in the new SUB. In November of 2010, students performed a triple bottom line assessment on the possibility of installing an energy monitoring display in the SUB. As a part of that study, they asked people in the SUB the following questions:

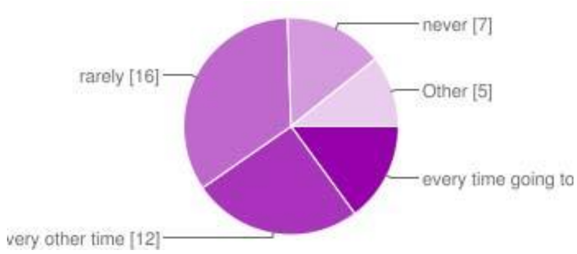
If there were a display monitor set up in a common area in the new SUB displaying the energy uses would you be interested in this information?



Yes	**38**	81%
No	**9**	19%
Other	**0**	0%

Figure 2: Energy display monitor survey 1, (2010)

How often would you purposely go look at the display monitor if there were one in the new SUB?



every time going to the sub	**7**	15%
every other time	**12**	26%
rarely	**16**	34%
never	**7**	15%
Other	**5**	11%

Figure 3: Energy display survey 2, (2011)

(Brad Burt, 2010)

These results show that students care about their energy usage and would likely be even more enthusiastic about an interactive exhibit like Pavegen.

Manufacturing the Parts

Each step in manufacturing a tile is done within 200 miles of the main office in London. This means that transportation related environmental costs in the form of greenhouse gas emissions are reduced. While Pavegen is to be commended for this practice, the transportation costs of shipping the product to Vancouver will most likely have a negative impact on public perception. Additionally, being manufactured in England, there are no human rights concerns with respect to unethical working conditions.

Perceived Product Outlook

One of the biggest issues with this project is its high associated cost. The price for the 8 tiles is ~$30,800 up front, and the lifetime of each tile is an estimated 5 years. Living costs at UBC and the Point Grey area are high, and as a result, students are especially critical of how their tuition is being spent. Students and faculty may have a negative perception of the steps if they feel there were better ways to spend $30,800, (the biowall, energy generating gym). There is also the possibility that the steps, which are meant to portray green technology in a positive light, could have the reverse effect if they are frequently out of commission being serviced or replaced. It may create an impression that innovative green technology is not as reliable as conventional energy from fossil fuels.

There's also a social issue concerning the environmental impact of the Pavegen tiles. Each tile is carbon positive; meaning the carbon produced during manufacturing and recycling, is greater than the carbon saved through generating power. At this point, the Pavegen tile is not green at all. This product attribute is contrary to the goal of sustainability through carbon neutrality in the new SUB.

Getting Students More Involved

The Pavegen tiles are a brand new technology and will likely change over the next several years. It's recommended that UBC hold off from purchasing 8 tiles when newer and better things may be available in the near future. There are other options to use piezoelectricity and opportunities to harness the ingenuity of the entire UBC student body to develop other ideas.

5.0 ENVIRONMENTAL IMPACT

To determine whether or not the Pavegen tiles are an efficient and sustainable form of power generation, we investigated the materials and processes used in making the tiles. As the Pavegen tiles are only manufactured in Europe, we also considered the environmental impact of transportation. To evaluate the tiles we separated them into their 4 primary components: concrete base, stainless steel casing, rubber surface and the lithium polymer battery.

Transportation

Green house gases (GHG) have become a major concern in recent years. Carbon dioxide (CO_2) is a major contributor to GHG emissions. Approximately 2% of global GHG emissions come from aviation. This number is expected to rise 3-4 % per year (International Civil Aviation Organization, 2007). Aircraft emit GHG's (nitrogen oxides and hydrocarbons) directly into the troposphere, increasing the concentration of tropospheric ozone (Colin Johnson, 1992).

As previously mentioned, the Pavegen tiles are only available in Europe, and must be flown to Vancouver to be installed. The transportation of supplies, as well as any future maintenance/replacement (to be done by a qualified Pavegen technician), will generate more GHG's than a local alternative.

Lithium Polymer Battery

Batteries in general are not environmentally friendly and it is well known that the improper disposal of batteries has a detrimental effect on the environment. Along with the environmental concerns, there is also a health issue associated with cracked or damaged batteries due to their toxic electrolyte. If a battery is disposed of incorrectly, (thrown in a landfill), the outer casing corrodes. This releases toxins into the surrounding soil, resulting in contaminated groundwater which eventually affects people, plants and animals.

The Pavegen tiles use Lithium Polymer (Li Po) batteries, which can still be dangerous to the environment if not cared for properly. However, the proper disposal of Li Po batteries is relatively simple, (neutralize in salt water and dispose of in household garbage). The Li Po batteries are distinguished from Lithium ion batteries because they use a solid polymer electrolyte rather than an electrolytic solution. A solid polymer electrolyte is what defines a "dry cell" battery. Dry cell batteries carry a reduced environmental/health risk as their internals are not liquid, therefore leakage is not a concern. A solid polymer electrolyte is much more flexible resulting in a battery that's less likely to combust under duress. Also, Li Po batteries contain no heavy metals, such as lead, nickel, or mercury. (Sun-wook, 2001) A lower risk of leakage/explosion and the absence of heavy metals make Li Po batteries more sustainable than conventional alternatives.

Rubber Surface

The contact surface of the Pavegen tiles are made from 100% recycled rubber. Using recycled rubber reduces the number of tires that are disposed of in landfills. Rubber in landfills has become a major environmental problem. During the production of rubber, harmful additives such as stabilizers, flame-retardants, colorants and plasticizers are introduced. If rubber tires are disposed of in landfills, the substances added during manufacturing can leach into the environment killing all the bacteria that would naturally break down the garbage (Adhikari, De, & Maiti, 2000).

When recycling rubber tires, they must first be detoxified, degraded and de-vulcanized before they can be processed. Once the rubber has undergone de-vulcanization it can be mixed with additional natural rubber and other chemicals, and then be re-vulcanized and made to fit many applications (Stallwood, Stevenson, & Hart, 2008). Some uses for recycled rubber are, padded sports mats, shower tiles, and truck bed mats.

Concrete Base

The concrete base of the Pavegen tile is not Ordinary Portland Concrete (OPC) as used in buildings, bridges etc. The concrete is composed of 30% to 70% Ground Granulated Blast-Furnace Slate (GGBS), an additive that partially replaces the OPC. Concrete made with GGBS has several prominent features making it a more desirable building material. GGBS, has a carbon footprint close to zero, (~30kgCO2/tonne of GGBS) (EcoCem). GGBS concrete is also stronger, has a longer lifetime, and is more resistant to salts and acids, than OPC concrete.

Stainless Steel

Stainless steel (>90% iron) is manufactured in two different processes. The first process takes iron ore and extracts the iron using a blast furnace. The second process makes use of recycled steel using an electric arc furnace. A large current is passed through the material to melt it, at which point additives can be added/removed to change the grade of the steel. Approximately 80% of stainless steel is manufactured using recycled steel and an electric arc furnace (ISSF, 2009). The CO_2 emissions associated with manufacturing steel from raw materials is 4.2 tons CO_2 per 1 ton of stainless steel. However, if recycled materials are used, the CO_2 emissions are reduced by approximately 30% (2.8 tons of CO_2 per 1 ton stainless steel) (International Stainless Steel Forum, 2010). The Pavegen tile's outer casing is made from 100% recycled marine grade stainless steel (~5% more chromium than regular stainless steel). The use of recycled materials has a significant impact on the overall carbon footprint of each unit, however, manufacturing any type of steel is still very energy intensive, (600kW for a 130 ton furnace). (Y.N. Toulouevski, 2010)

6.0 CONCLUSIONS AND RECOMMENDATIONS

Based on our triple bottom line analysis of the Pavegen tiles, we were able to draw clear conclusions about the feasibility of the project in its current form. Firstly, the Pavegen tiles are expensive. They generate very little power, but the generation method is unique and interactive. As a result of the user interface with the product, there is good potential for the steps to get people thinking about alternative energy. However, there are negative effects associated with people thinking of Pavegen tiles as an example of alternative energy generation. Of primary concern is that the tiles are expensive, carbon-positive and have a short service life when compared to conventional energy generation methods as well as green technologies that operate on a similar scale.

In summary, we have developed a pro and con list for the current project specifications:

Pro	Con
• Innovative • Unique • Interactive	• Expensive • Ineffective in terms of energy generation • Not local technology • Carbon positive • No warranty • New technology, concerns about reliability • Relatively short service life

Table 2 Pros and cons of the Pavegen tiles

As can be seen from the above list, the negative aspects of the Pavegen project heavily outweigh the positive. We believe that the current proposal for an installation of Pavegen tiles should be either abandoned or modified. Over the course of our analysis, we developed the idea of an interactive ‘green corner’ in the new SUB. This space would essentially be a showcase of innovative, new or unusual ‘green’ technologies such as a biowall, an energy-generating bicycle, an energy consumption display board and 2-4 Pavegen tiles. In this scenario, a person’s interaction with the tile would be deliberate and more personal than walking over an array of tiles in a large crowd of people.

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