HydroGen - Electricity Production from Waste Water

http://www.ee.ic.ac.uk/siddharth.garg13/yr2proj/default.htm

2nd Year Group Project: Final Report

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Abstract

HydroGen is inspired by the idea that the kinetic energy of falling rainwater can be harnessed to generate electricity. The product integrates seamlessly into rainwater pipes (known as downpipes) which are, at present, used to form rainwater drainage systems. Installing HydroGen requires no significant changes to current plumbing systems and will benefit users with reduced bills in an environmentally friendly way. The design process involved the evaluation of four different concept designs before the product could be developed. In addition, low level testing was done to determine how much energy could be generated and which additional components would be necessary to make the product work effectively. In the end, it could be concluded that, if further developed, HydroGen would be economically viable despite its current limitations.

Introduction

The primary aim of this project is to design a product which generates electricity from rainwater and stores it in rechargeable alkaline batteries. Buildings are usually equipped with suitable drainage systems which channel rainwater to flow through downpipes. Ideally it should be possible to easily implement the product into such a system.

The product is aimed at people living in areas affected by high volumes of rainfall. In a survey conducted by the group where 86.89% people confirmed that they live in a rainy country, it was indicated that most people are not satisfied with their current energy bill and are interested in finding ways to reduce their energy bills. This survey demonstrates that given the product is priced correctly and can execute the tasks it was designed to perform, it would be commercially viable.

In the first stage of the project, several concept designs were considered. The group used a decision matrix system to justify the final decision on which concept design to use. The final concept is best explained in terms of the energy conversions which take place in the system. Firstly, rainwater has gravitational potential energy at the top of the downpipe. As it flows down, this is converted to kinetic energy. When the water makes contact with the water wheel, its kinetic energy is converted to mechanical energy, which is then converted to electrical energy as the wheel turns a dynamo via an axle.

Using high and low level designs for the product, the group tested under a variety of simulation conditions. This provided important data about how much energy can be produced and what the best way to produce it would be.

Design Criteria

The main points of the revised design criteria are as follows:

Performance – The product should harvest energy from rainwater or solid free waste-water from the drainage system of multi-storey buildings, to produce electricity. Any energy that can be stored is beneficial as it would otherwise be lost.

Maintenance – Once installed the device should require minimal maintenance throughout its lifetime. This is to ensure users are not hassled by the product and deterred from using it.

Size – The entire mechanism should fit in with existing standard 65mm diameter pipes of rainwater drainage systems so as to be easily implementable and non-obtrusive to existing plumbing structures.

Weight – The product should be light enough to attach within and be supported by existing pipes in buildings to ensure no plumbing issues occur such as ruptures or leakage.

Materials – The majority of the design should utilize plastic components to keep it lightweight and waterproof. The main parts needed are a PVC (polyvinylchloride) pipe, 3D printed polymer water wheel and a plastic compartment to confine electrical components. The electrical components such as the generator and circuitry should be purchased from standard suppliers to allow current flow.

Ergonomics – The product should be self-contained and require minimal user interaction. Besides initial installation and periodic checks it should remain unobtrusive to the consumer as any regular pipe part of the rainwater drainage system.

Political and Social Implications – The product should serve as a "green" energy source, harvesting energy from rainwater which would otherwise be wasted. Installation would aid areas with intermittent power supplies, especially rural areas, while also assisting communal devices such as building intercoms in well developed areas. Governments can factor this green energy in their annual generation schemes and benefit from international approval for protecting the environment. Overall the product should improve living standards while conserving the environment.

Installation – The product must integrate into existing piping systems such that a plumber can easily replace a portion of the drainpipe to install it. There will be a cost associated with hiring the plumber unless the system is installed while a particular building is being built.

Disposal – Initially **c**onsumers can dispose the product in government appliance disposal schemes. If the product proves successful and business flourishes a recycling department can be added to the business so customers may return the product. Any functioning parts will be salvaged for new product manufacture, recyclable parts recycled and any remaining components sent to landfills. This way the company will reuse, reduce and recycle, strengthening its environmental friendliness.

Safety – Electrical parts must be enclosed in a well-insulated container to eliminate risk of electric shock. Preventing water leakage from the pipes and sealing any physical connections with the compartment will limit electrical accidents.

Consideration of various concept designs

As the primary focus of the project changed from the initial idea, several concept designs were formed. This section briefly describes each of the various concepts that were considered.

Concept Design 1

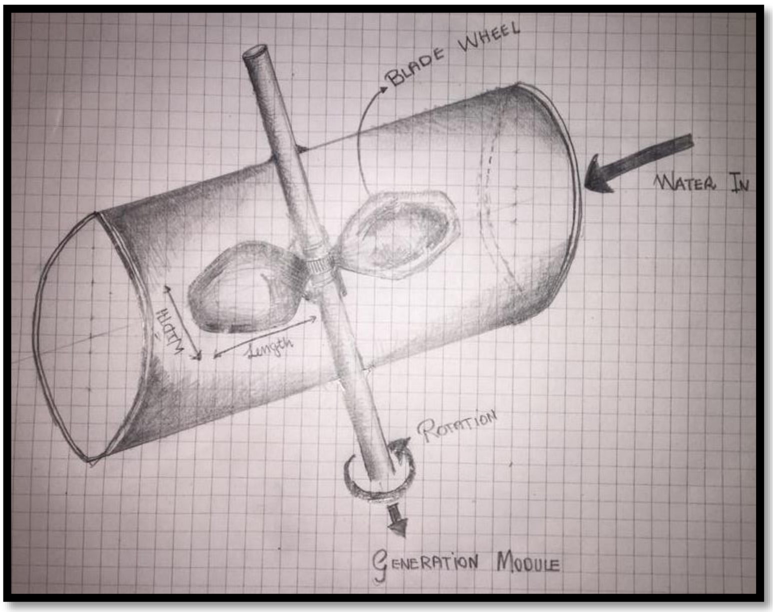

Figure 1: Concept Design 1 Diagram

Design 1 implements a blade wheel electricity generation system (BWEGS) in a bath tub plumbing system to convert potential energy into kinetic energy. The blade wheel is constructed using 2 PVC blades sized to fit securely within sealed drainage pipes. Water is directed into a small volume and forced at high speeds past the blades, resulting in them turning and converting energy. The BWEGS system will be fitted by replacing a segment of the existing waste pipe as shown in Figure 1. Limitations like insufficient pressure build-up due to limited height drop and restricted water volume, leakage issues with the rotating axle penetrating the pipe and possible drain clogging from debris deemed this design infeasible.

Concept Design 2

The limitations of insufficient pressure and restricted volume of water in Concept Design 1 were improved by installing a water tank underneath the bathtub as seen in Figure 2. The water tank's inlet and outlet are equipped with a check and relief valve respectively to prevent backflow and ensure sufficient water flow is maintained by accumulating enough water in the tank. Concept Design 1 is then incorporated beyond the outlet pipe which ultimately connects to the main drainage system, indicated by "water out" in Figure 2.

Despite increasing water volume, due to the difficulty in achieving substantial pressure levels it was not possible to spin the blade wheels. The tank would be impossible to fill to its entirety as once it begins to gradually fill up, water pressure inside the tank will exceed that of water entering it. Additionally an average tank of dimensions 0.09m x 0.5m x 0.5m proportioned towards a regular bath tub would only hold 0.0225m^3 – a volume too small to produce considerable amounts of kinetic energy.

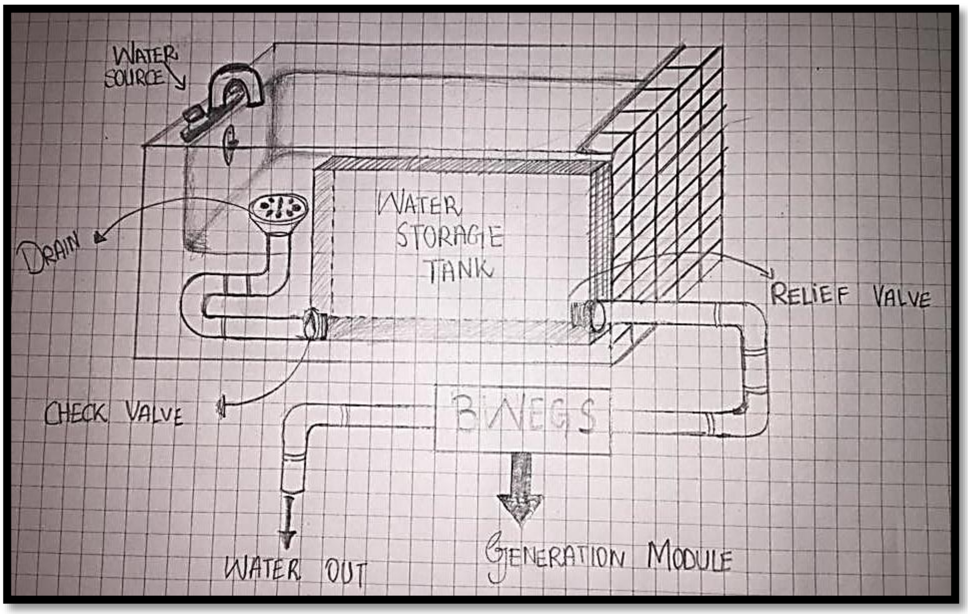

Figure 2: Concept Design 2 Diagram

Concept Design 3

Concept designs 1 and 2 both involved the sole utilisation of the drainage system of a bathtub. The combination of their potential flaws drove the group to implement the system after the junction pipe connecting all three waste-water sources (bath toilet, and sink) in a house. Here the average flow rate is higher as the lack of height drop is now negated.

Figure 3 illustrates the location where the product is envisioned to be placed. As waste water drains from the sink, toilet or bathtub, the water travels through the pipe and hits the blades, causing them to spin. This design can especially be considered for high-rise buildings where numerous waste-water sources on multiple levels can be utilised. Placing the mechanism as low as possible in the pipe will maximise the height drop and consequently the force produced to turn the blades. Despite counteracting small height drops and associated low water pressure a new issue of filtration arose. Implementing the product after the junction pipe introduces large amounts of debris, significantly faecal matter. This requires an effective filtration scheme to be used to prevent clogging of the blades. Without the filter the reliability of the system is extremely poor and would demand higher maintenance by the user, exactly the opposite of what is stated in the PDS.

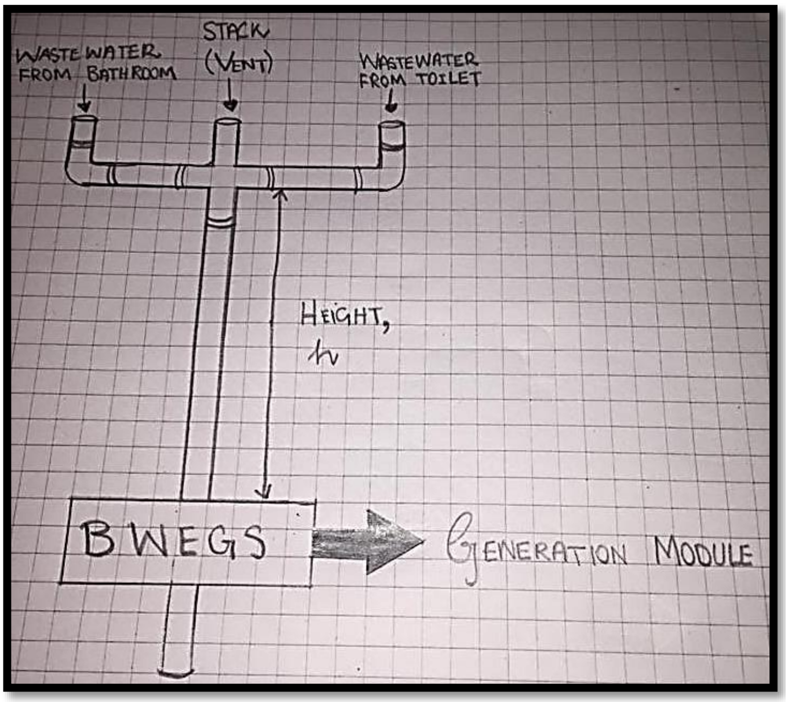

Figure 3: Diagram Demonstrating Concept Design 3

Concept Design 4

Concept designs 1 and 3 were collaborated to implement an energy harvesting device in rainwater pipes, known as a down pipe, see Figure 4 in the 'Final Design Concept Illustration (FDCI)' section**.** In the UK down pipes are widely used to avoid wall dampening during rain fall. Already installed in most buildings they require consumers to purchase no further equipment besides the product. Additionally, these pipes are fitted over ground so can be easily accessed compared to those fitted under tiling and behind walls. Again, it requires cutting a section of the down pipe and replacing it with the product secured inside a pipe of similar diameter. This is outlined by figure 5 in the FDCI section. In fact consumers with slight plumbing knowledge could carry out this procedure themselves without requiring the help of a professional plumber. This reduces involved costs and renders the mechanism more marketable.

The key advantage of utilising down pipes is their presence of filters and guards to prevent debris such as leaves, moss, twigs and so on from entering and clogging the pipe. This is crucial for this idea to work because blockages would reduce conversion efficiency and could potentially jam the whole mechanism. Since guards and filters are widely available in the market, it is unnecessary to design one.

Having sorted out the pressure and force aspect of the design already in Concept Design 3, there is also the issue regarding amount of rainfall. In the UK rainfall is a common occurrence[1] but takes place in varying amounts with differing intensities. To deal with this varying volume of rainfall, the design implements a water wheel to ensure energy output while even the meekest of downpours. The water wheel is placed half in and half out so all the rainwater within the pipe hits it while allowing it to spin freely, see figure 5 in the FDCI section.

Final Design Concept Illustration

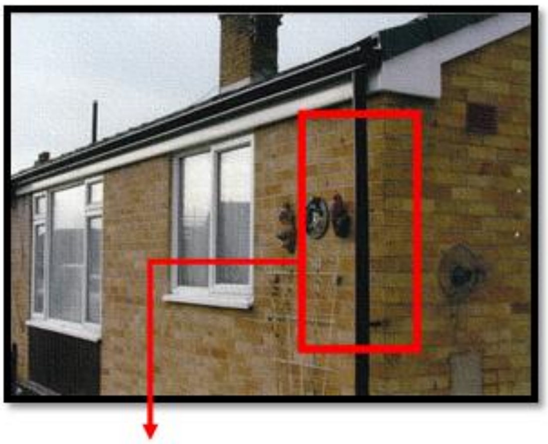

Figure 4: Down pipes in a typical household

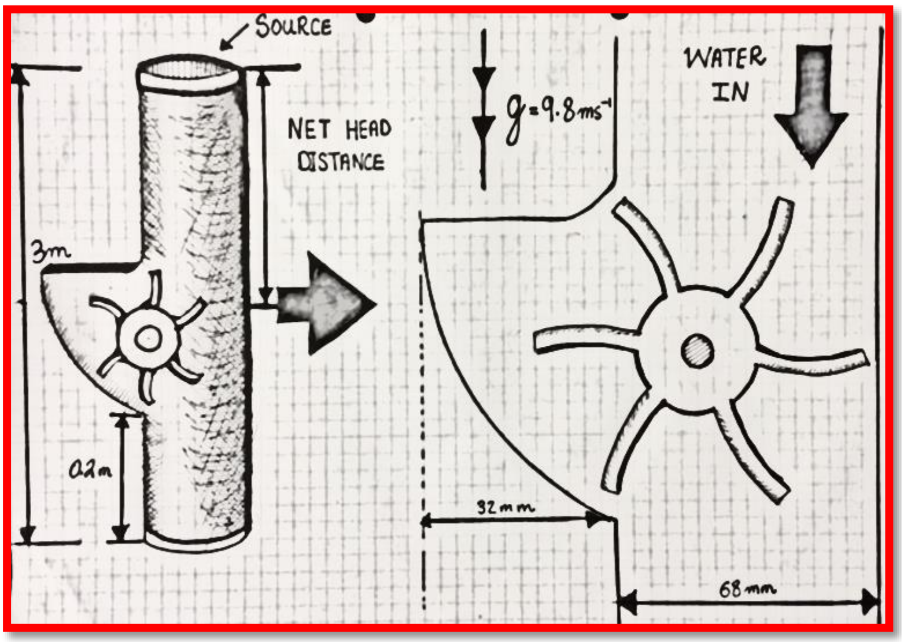

Figure 5: External design illustrated

[1] "How Much Does It Rain in the UK?" *Met Office*. N.p., 9 Feb. 2015. Web. 14 Mar. 2015. http://www.metoffice.gov.uk/learning/rain/how-much-does-it-rain-in-the-uk

The overall system is depicted in Figure 6 highlighting the assembly of the product within the pipe. The water wheel will be assembled from 3 parts. These consist of a fixed rod, a rotor and waterwheel mechanism which allow the wheel to rotate but remain in a stationary position at the same time. The second diagram on the right in figure 6 shows a cross-sectional, 3D point of view.

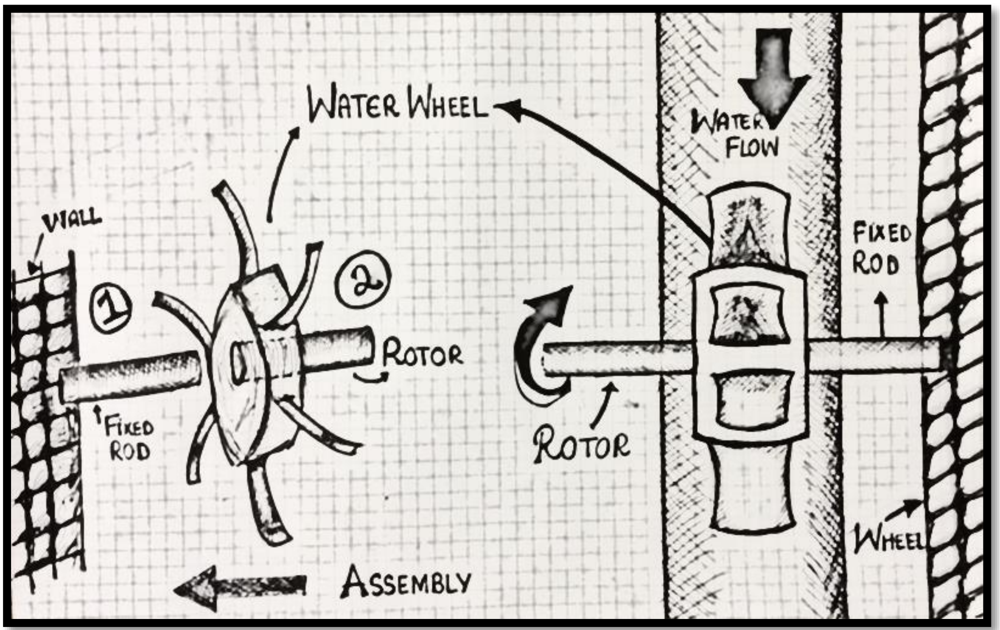

Figure 6: Internal design shown in detail

Rotations of the rotor will be utilised to produce electricity. Initially a dynamo was to be utilised for generation as it produce direct current, DC, which is what rechargeable batteries require. Alternating current, AC, changes polarity at 50Hz or 60Hz which is too fast in comparison with which batteries can change their own polarities. However it was later decided a motor would be better suited than a dynamo. As this leads to AC generation, a rectification stage is needed to extract DC which can then power rechargeable batteries.

Concept Selection

Considering the limited time availability and feasibility of this project, several business strategies were adopted to ensure the project is carried out successfully. To begin with, surveys were conducted through social media and at different universities to assess the potential demand for our product. A total of 120 people were surveyed ageing from 18 to 45 at different universities across London. Before taking the survey, the conceptual design for the project was explained. In the case when it was conducted online, a brief introduction video was shown to the survey taker regarding the product. The results for the survey are shown in Figure 7:

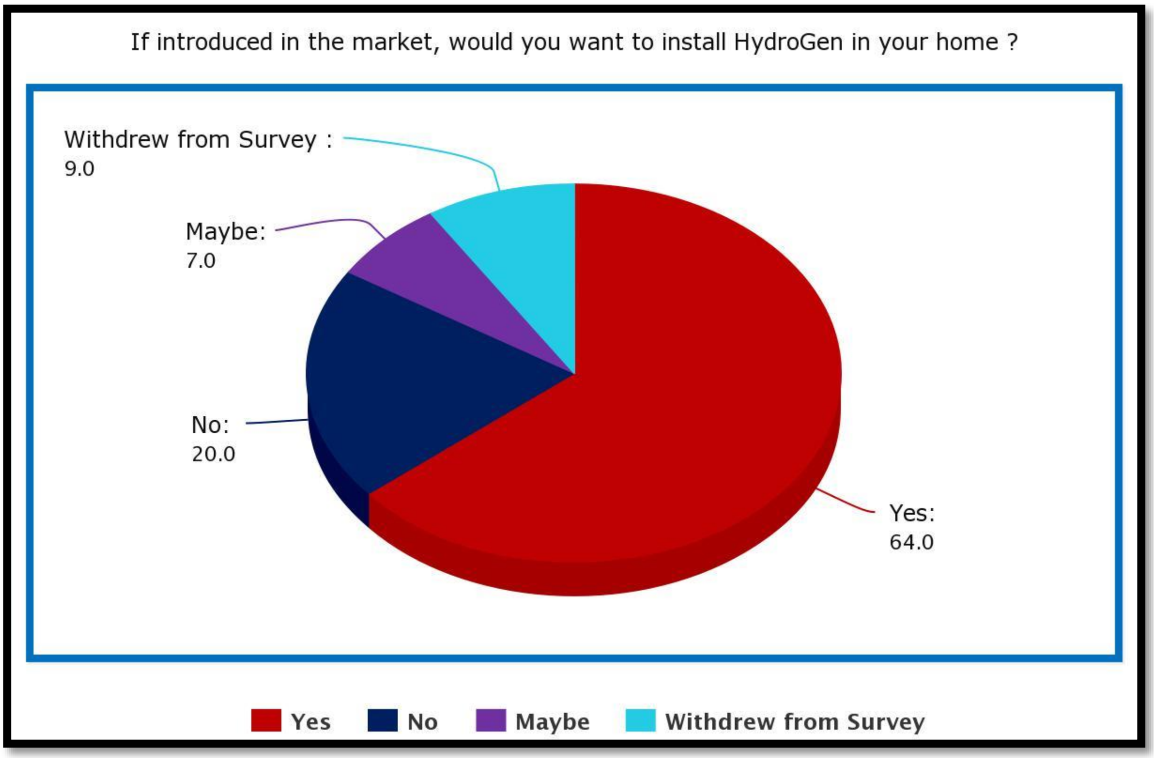

Figure 7: Pie chart highlighting results of survey

It is evident from survey results that demand for such an electricity generation system exists in the market and once this system is developed, it has the potential of being introduced globally focusing on rural villages that have limited access to electricity[2]. This could potentially help a country stabilize its balance of trade. It must be emphasized however that the system to be used by the team would only be implementable in countries where rainfall is in abundance.

Like every other project, several solutions were proposed by team members on different electricity generation systems. After careful analysis, three fundamentally different conceptual designs (Designs 2, 3 and 4) were shortlisted. Each method was evaluated considering various factors and a decision matrix was used to finalize the concept design to be used. This strategy led to a systematic project evaluation and the final decision matrix used is shown in figure 8 below:

[2] "Rainwater Harvesting." *Rainwater Harvesting*. N.p., n.d. Web. 14 Mar. 2015. http://12.000.scripts.mit.edu/mission2017/solutions/engineering-solutions/rainwater-harvesting-techniques/

Decision Matrix for Concept Designs

Decision Model		Concept Designs					
		BWEGS and Tank System		Drainage System		Rainwater Pipe System	
Criterion	**Weight**	**Rating**	**Score**	**Rating**	**Score**	**Rating**	**Score**
Cost Effectiveness	30	1	30	1	30	3	90
Energy Generation	30	1	30	3	90	3	90
Feasibility	40	2	80	2	80	4	160
Total	100	4	140	6	200	10	340

Score = Rating * Weight

How to rate an option?

Rating	Description
0	Poor
1	Low
2	Moderate
3	Above Average
4	Excellent

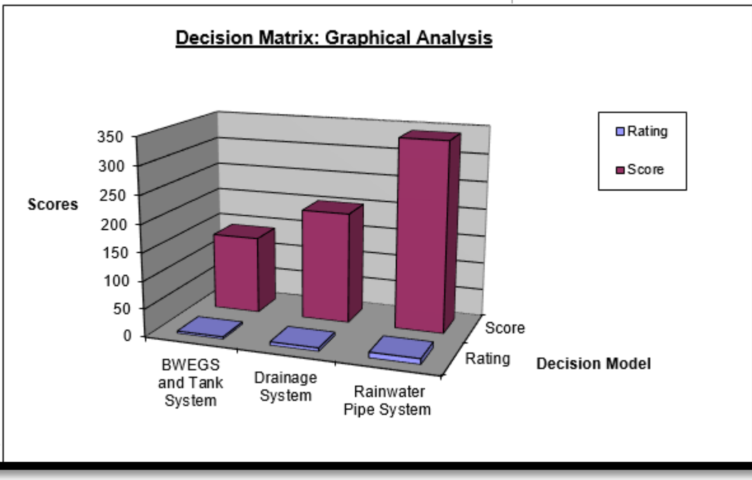

Figure 8: Decision matrix to determine final concept design

Three factors were given priority to decide which method the team should go forward with. Feasibility is given the highest weight in order to ensure the project is manageable given the time constraint. As apparent from the graphical results, rainwater pipe system deemed to be the most viable concept design.

Competition

The fundamental concept idea behind the product derives from hydroelectric electricity generation. The flow of water drives a generator to produce electricity. It follows that hydroelectric generators would ideally be implemented in places where there is fast flowing water. The intention, in this context, is to generate renewable electricity at an industrial level which is both cost and energy efficient in an attempt to combat the adverse effects of electricity generation from fossil fuels.

In this way, although the concept idea behind the product is well documented and already implemented on a wide scale, it is for a completely different context. HydroGen seeks to generate small amounts of energy from a source which would otherwise go to waste. The size of the product is much smaller, and efficiency is less important because the product is relatively cheap.

One particular potential competitor could be De Montfor University student Tom Broadbent's HighDro Power, which "turns falling wastewater into electricity." Similarities with the group's product include the use of a waterwheel-like turbine, and the use of the kinetic energy of flowing water to generate electricity. Once again, the difference lies in context. HighDro Power is to be implemented in series in tall buildings, taking in the collective waste water from the building's plumbing system, and returning "power either to the building itself or to the grid."[3] One significant difference in his device would be that he must account for a method of filtration to deal with solid waste as well.

There could also potentially be competition in the form of people using microbial fuel cells to generate electricity. Although the method of extracting energy from waste water is different, the idea is still similar as it involves the generation of electricity from waste water. A microbial fuel cell extracts energy from bacteria to generate electricity and simultaneously treats wastewater.

Finally, the Pluvia system developed by Omar Enrique Levya Coca Romel Brown, and Gustavo Rivero Velázquez represents the most likely competitor. It "uses the stream of rainwater runoff from houses' rooftop rain gutter to spin a micro turbine in a cylindrical housing. Electricity generated by that turbine is used to charge the 12-volt batteries, which can in turn be used to power LED lamps or other small household appliance. Once the water has flowed through the micro turbine, it proceeds to pass through a charcoal filter and into a storage tank."[4] In this way, in addition to generating a small amount of electricity from rainwater, the Pluvia system also cleans the water and stores it in a tank ready for use. This is one difference which adds utility to their product, but which should also, in theory, make the product more expensive. Another major difference is that, letting the rainwater flow directly down the pips, "rain is collected and stored, then pumped to the micro turbine…according to IEEE Spectrum, the pump mechanism currently needs more power than the turbine generates.[5]" The build-up and release of rainwater is presumably to increase the flow rate and turn the micro turbine faster. However, the use of the pump makes their device currently inefficient as overall, power is being lost from the system. Nevertheless, it is still a potential competitive product under development.

Originality

Various concept designs were considered for engineering a product which can generate electricity by harnessing the kinetic energy of flowing waste water in drainage pipes. The research involved an analysis of plumbing and various options for both the generation and conversion of the energy.

Despite similar systems being existent in the market, it was vital to ensure that the final concept idea incorporated a reasonable element of originality. In other words, the idea should have a novel approach to an existing question. In this case, the question is 'How to utilise waste-water effectively to produce electricity?'

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[3] "Microbial Fuel Cells." *Microbial Fuel Cells* (n.d.): n. pag. *Research at Penn State*. Penn State University. Web. 15 Mar. 2015. http://www.research.psu.edu/capabilities/documents/MFC_QandA.pdf

[4] Coxworth, Ben. "Rainwater Used to Generate Electricity." *Gizmag*. N.p., 26 Mar. 2014. Web. 14 Mar. 2015. http://www.gizmag.com/pluvia-rainwater-microturbine/31379/

[5] Brownell, Blaine. "Pluvia Generates Energy from Rainwater." *Architect Magazine*. N.p., 30 Apr. 2014. Web. 14 Mar. 2015. http://www.architectmagazine.com/research/pluvia-generates-energy-from-rainwater_o.aspx

For example, according to a British middle-market tabloid ‘Daily Mail’, researchers have been able to power an LED with a single drop of water. The article states that there is significant hope of scaling this system up where it could be used for water from flushing toilets. [6]

Hence why using waste-water produced from a bathroom including toilets and bathtubs were considered as a potential concept idea as it doesn’t readily exist as a product or service on the commercial market. However having compared different conceptual design ideas, group chose not to proceed with this particular one.

In addition, the novelty of harvesting rainwater and literally funnelling the water through pre-existent gutter pipes to drive small waterwheels is not comparable to expensive and relatively huge rainwater harvesting systems such as the one mentioned below. The two systems are fundamentally different in terms of functionality and the equipment involved.

According to another British national daily newspaper ‘The Guardian’[7], the Graf system is a rainwater harvesting system that plumbs into your home. However a key difference to this design is that it involves a massive storage tank to preserve the harvested rainwater and then it passes through a turbine. Also, the main drawbacks of the system such as high-cost and the ease of implementation may potentially affect the demand for the product.

Concept Development

High Level Design

Figure 9 shows the high level design of wastewater electricity generation system which consists of an initial mechanical system module followed by a generation module. Rainwater is used as an energy supply for the whole system. As potential energy changes to kinetic energy, the water strikes the waterwheel causing the waterwheel to rotate.

The waterwheel is connected to a steel rod which has fixed gears on the other end. As this gear rotates it causes another smaller gear connected to the motor to rotate. Big gear to small gear ratio is 10:1, hence the gear on the motor has ten times the angular velocity of the waterwheel. Electricity is produced

[6] Zolfagharifard, Ellie. "Water Good Idea! Scientists Manage to Harvest Electricity from TOILET FLUSHES." *Mail Online*. Associated Newspapers, 21 Apr. 2014. Web. 14 Mar. 2015. http://www.dailymail.co.uk/sciencetech/article-2609475/Water-good-idea-Scientists-manage-harvest-electricity-TOILET-FLUSHES.html

[7] Ferguson, Donna. "Rainwater Harvesting: Using the Weather to Pay Your Bills." *The Guardian*. N.p., 22 July 2014. Web. 15 Mar. 2015. http://www.theguardian.com%2Flifeandstyle%2F2014%2Fjul%2F22%2Frainwater-harvesting-using-the-weather-to-pay-your-bills

when a rotating conductor inside the motor cuts the magnetic field[8] and hence induces an electromotive force (EMF). This EMF causes a current to be produced and hence electricity is generated.

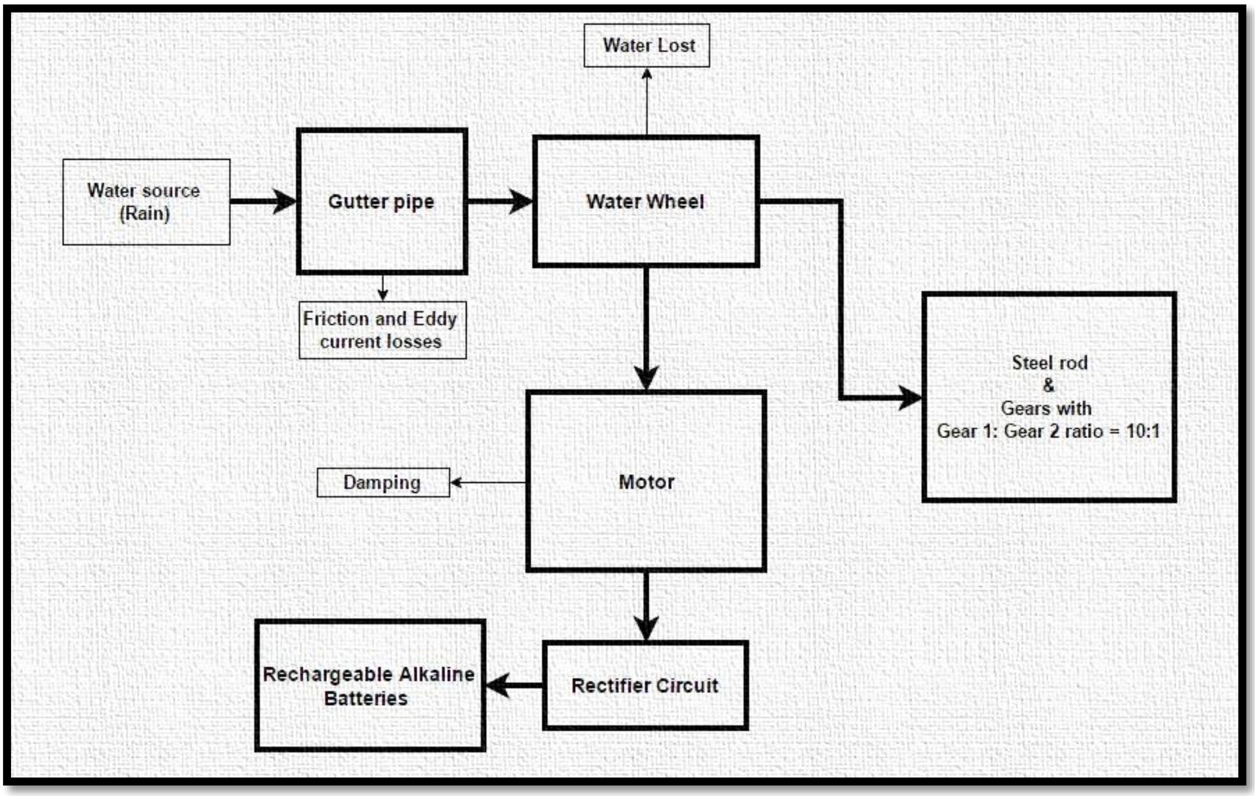

Figure 9: High-level design of HydroGen

The voltage induced is AC in nature and hence we must convert it to DC[9] to be able to store it in an alkaline battery. A simple rectifier circuit[10] is used to achieve this and hence current can flow into the battery. The circuit therefore ensures rectification of AC signal produced and it also prevents any leakage current escaping from the battery.

At some stages the loss of energy is highlighted will have significant impact on the final power produced by our product. Another concern that needs to be considered is the turbulent flow of the water which can result it in not hitting the wheel with sufficient energy and simply flowing past the water wheel blades. This can be tackled by channelling the water to flow on one side of the pipe to ensure water

[8] Markus Zahn, *Electromagnetic Field Theory*. (Massachusetts Institute of Technology: MIT OpenCourseWare). http://ocw.mit.edu (accessed 03 15, 2015). License: Creative Commons Attribution-NonCommercial-Share Alike.

[9] "DC Motor." *MathWorks*. N.p., n.d. Web. 14 Mar. 2015. http://uk.mathworks.com/help/physmod/elec/ref/dcmotor.html

[10] "AC to DC: Using a Full-wave Diode Rectifier." (n.d.): n. pag. *EECS Instructional and Electronics Support*. University of California, Berkeley. Web. 15 Mar. 2015. http://www-inst.eecs.berkeley.edu/~ee100/fa05/Labs/finalpart1/full-wave%20rectifier.pdf

strikes the blades and to prevent accumulation of water on the other side. Another factor that would affect the power output efficiency is the motor itself. The motor has imperfections such as “windage”/friction loss, iron loss, stator and rotor copper loss. The current motor being used in the system is capable of achieving an efficiency of about 85% or greater.

Despite water wheels being less efficient than turbines[11], they are much more viable when it comes to producing electricity for small power devices. They are useful for situations with requirements such as a net head of about less than 5m. In addition, water wheel eliminates the need for complicated control systems due to its simplicity in design. [12]The drawbacks are that they spin relatively slowly and require a high ration gearbox to drive a generator. In our case, the gear ratios are 10:1 which is fairly large considering the size of our system.

In deducing the power produced by this water wheel, two important factors to consider are the flow and head of the water that flows through the wheel. In this case, the source of water is the rainwater flowing through the gutter pipe. It is apparent from Figure 5 that the net head distance is the distance from the source of the falling water (initial opening of the gutter pipe) to the water wheel. The flow rate is volume of water falling per unit time. Hence the equation used to calculate power output of the water wheel is:

$$\boldsymbol{Power = Head \times Flow \times Gravitational\ acceleration}$$

Low Level Design

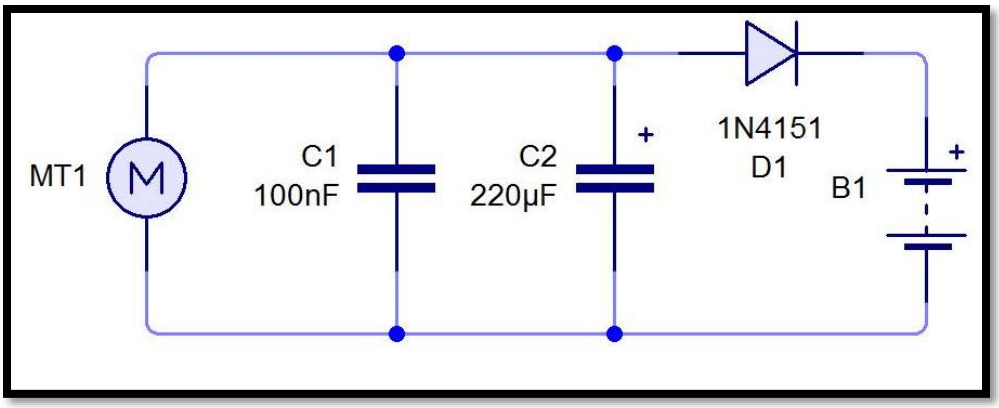

Figure 9: Low-level design of HydroGen

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[11] Horton, Robert E. *Turbine Water-Wheel Tests and Power Tables*. N.p.: Washington Government Printing Office, 1906. Print.

[12] "Waterwheels." *British Hydropower Association*. N.p., n.d. Web. 14 Mar. 2015. http://www.british-hydro.org/waterwheels.html

Most complex control circuits use more power than this device can generate, hence the need to precisely control power is unnecessary. The battery will slowly trickle charge and consequently the risk of damaging it by over supply is low.

Capacitors smooth the rectified sine wave from the motor to try and keep it at a constant voltage and remove the noise that will be created.

The diode prevents the battery discharging through the circuit shown in unfortunately it will take a lot of the voltage generated from the motor. A MOSFET was considered to replace the diode as its drain source voltage drop is roughly 0.2V in saturation, however, a MOSFET with low enough threshold could not be found. The input voltage at the motor is shown in figure 10.

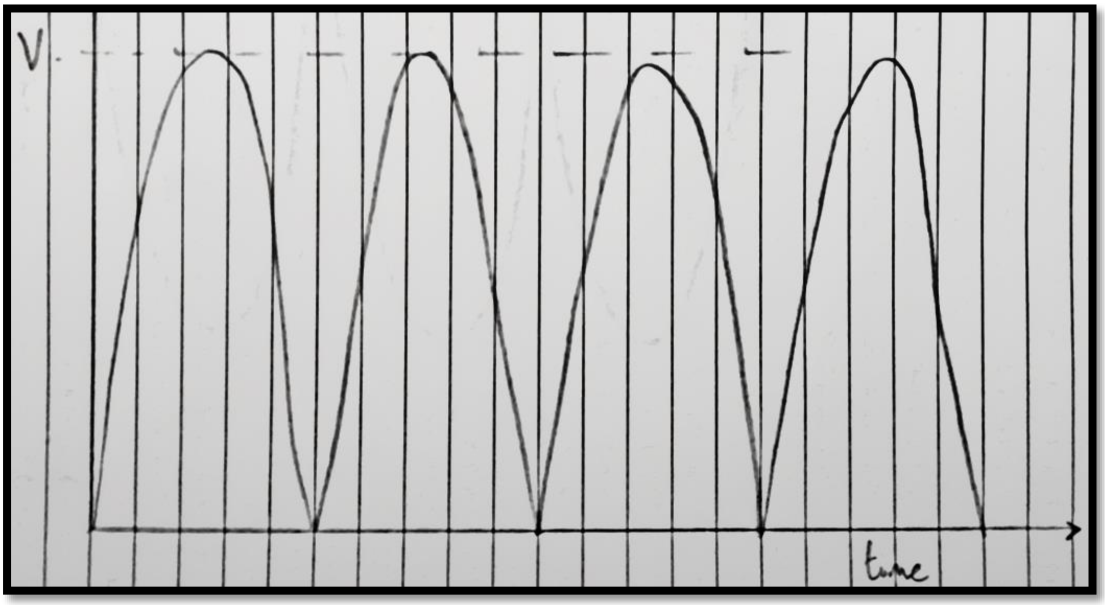


Figure 10: Input voltage waveform

The output voltage should ideally be a DC signal at the average voltage of the input wave minus the 0.7V dropped across the diode.

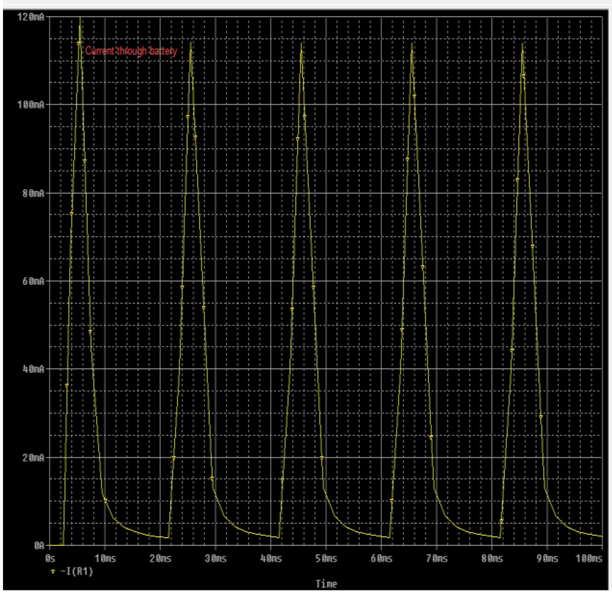
Discussion

Simulation & Testing

One of the many potential applications of the product includes charging smoke alarm batteries which are usually 9 volts. After having considered the datasheet for small standard sized batteries,[13] it was

[13] *Product Datasheet*. N.p.: Energizer, n.d. PDF. http://data.energizer.com/PDFs/HR22-175_EU.pdf

found that a good estimate for the internal resistance was 1000mΩ. Therefore for simulating the circuit a 1000mΩ resistor was used instead of a battery.



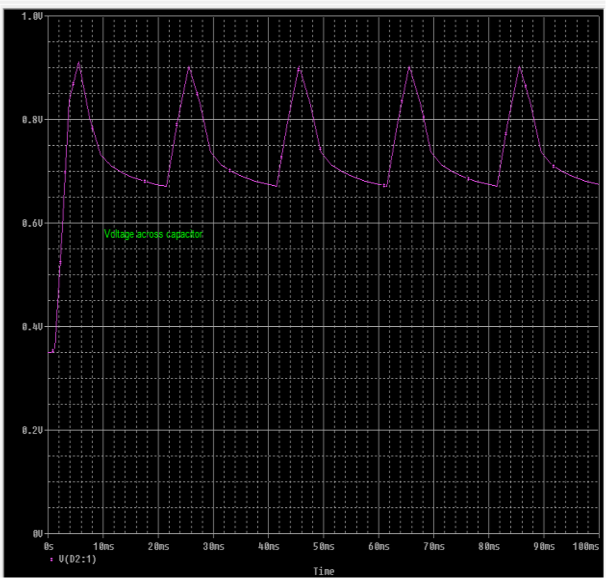


Figure 11: Current through the battery

Figure 12: Voltage across the capacitor

The circuit used for the simulations shown in figure 10 and 11 is circuit shown in the low-level design (Figure 9) except the battery was replaced with a 1000mΩ resistor.

Estimation of Power Output

Testing of the proposed water wheel design was essential to estimate the power generated by the system under optimum conditions. A water wheel was designed using SketchUp (Figure 13) and then successfully printed using a 3D printer. However extensive testing was not possible due to many restrictions in the lab. Firstly the water wheel was directly connected to the motor to get a rough indication of the power output of the combination of both the wheel and the motor. Performing such as test would provide a reasonable simulation of the system being used under optimum conditions.

To carry out the test as well as simulate optimum conditions would result in having to generate a source of water with a reasonable flow rate and net head distance. Ideally, the water source should be vertically aligned in parallel with the water wheel. As soon as the water wheel achieves a constant spinning rate, the output from the motor can be connected to an oscilloscope to measure the output voltage, current and hence the power output could be deduced.

Unfortunately, this wasn't possible due to a breach of the safety regulations of the labs as large amounts of water needed to be present near expensive devices prone to sensitive water damage. Therefore an alternative approach was required to estimate the power output.

It was then decided to spin the water wheel manually by hand or through a lever to get an estimate of output at least produced by the motor. The output was put through a 1KΩ resistor. The readings on the oscilloscope were displaying a very low voltage (highest reading was about 800mV) and thus one may say this is not a reasonable power output. It was difficult to maintain a constant spinning rate and the voltage measurement displayed on the oscilloscope output kept on fluctuating between 100 and 800mV.

The overall output power that was being produced through physically spinning the wheel was ranging from 700mW to about 1W. But this is instantaneous power produced at a particular time thus it can be predicted that over a long period of time, sufficient power will be generated to gradually charge a small battery that powers a small device.

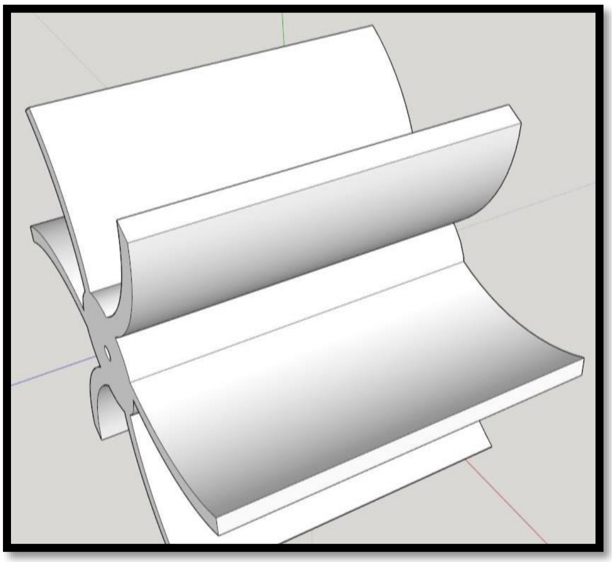


Figure 13: Water-wheel designed used SketchUp

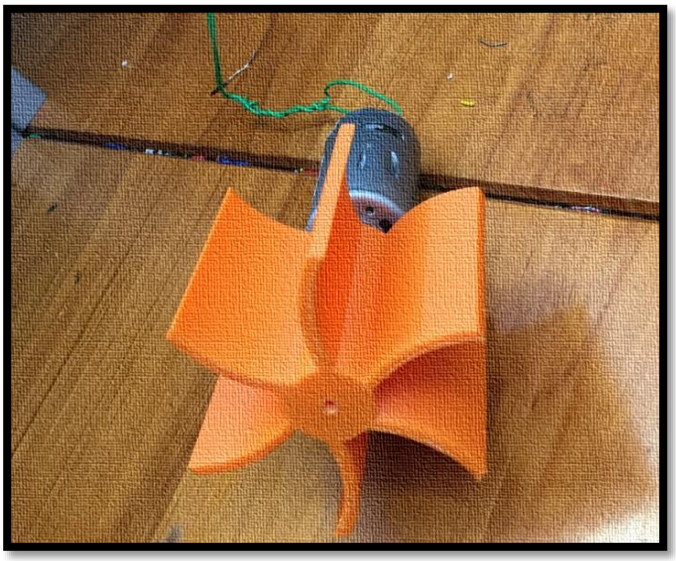


Figure 14: 3D printed water wheel

Simulating rainwater as a source of energy

Further testing was carried to simulate the rainwater hitting the water wheel. This was performed by utilising the tap water as a source of energy. With tap fully open the water wheel managed to produce reasonable spinning motion and approximately 1.0V DC was generated at the motor terminals, giving 300mV at the resistor output.

Varying the flow rate by adjusting the power of water using the tap it was possible to deduce that the system relied on a compromise between net head distance and volume of water from the source. At a larger height drop as opposed to a very low one in a tap situation, we have more energy per unit volume.

Therefore in reality when HydroGen is being implemented, it can be predicted that there will be sufficient flow rates present to generate a reasonable power output.

Tap flow rate is about 10litres/min[14] through a pipe of 2cm so speed of water is 0.053m/s, therefore the energy per second = $0.5 \times 1.66\times10^{-5} \times 0.053^2 = 2.3\times10^{-8}$ J/s

Average rainfall is roughly 60mm per month[15], with there being 15 rainy days. Average house size is approximately 80 square metres so the volume of water on top of the house is $0.32 m^3$ per rainy day

Volume of rain per day on a roof = $0.32\ m^3$

So every second there is $3.7\times10^{-6}\ m^3$

Energy of that water = m x g x h = $3.7\times10^{-6} \times 10 \times 4 = 1.5\times10^{-4}$ J/s

From these calculations it is clear that if the tap water could drive the motor then water falling from the roof should be able to do the same.

Simulating motor's output

The motor's output was simulated using a signal generator. Using a sine wave output with a 0.7V offset and passing this through a diode the resultant waveform was approximately the same as the motor. Instead of a battery, for this test a 1kΩ resistor was used instead.

The frequency of the wave was calculated from the rough calculations of the speed of the water driving it:

V = 10 x 0.9 = 9m/s

Radius of wheel 46mm so circumference = 0.28m
Revolutions per second = 30
So the frequency of the motor will be rotating in the range of 20 – 100Hz. For tests the signal generator was generating a signal with frequency of 50Hz. Figure 15 shows the absolute value of a sine wave with a shift of +0.7V. After passing through the first diode the signal loses the 0.7V offset and looks similar to what the output of the motor would be.

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[14] "Plumbers and Heating Engineers." *Harwood and Associates*. N.p., n.d. Web. 14 Mar. 2015. http://www.harwoodandassociates.co.uk/faqs/terminology/flow-rates/
[15] "London: Annual Weather Averages." *Weather Averages for London, United Kingdom*. N.p., n.d. Web. 14 Mar. 2015. http://www.holiday-weather.com/london/averages/

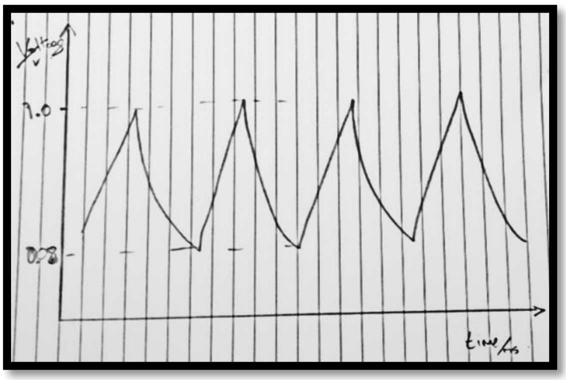

Figure 15: Waveform of motor input

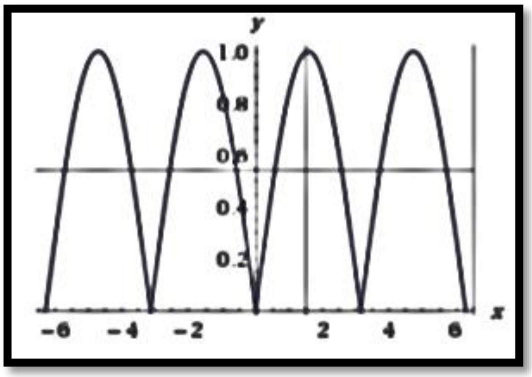

Figure 16: output waveform after passing through the control circuit.

The capacitor smooths the input, making it move constantly. Testing with larger capacitors decreased the difference between the maximum and minimum voltages of the output, however, at a certain size the capacitors began to reduce the maximum voltage. Increasing the frequency of the input also reduced the change in voltage, if the motor is geared up so it spins faster than the wheel it could reduce the variance in its output. After some investigation it was decided to use a 220µF electrolytic capacitor as the smoothing element of the circuit.

<u>Additional Considerations</u>

<u>Economic Feasibility</u>

Component Names	Quantity	Stock Number	Unit Price (£)	Total Price (£)
Brushed DC Motor	1	248-3671	9.86	9.86
Electrolytic Capacitor (220 micro Farad)	1	________	0.59	0.59
Diode (1n4008)	1	________	0.50	0.50
Water Wheel	1	______	(Estimate) 5	5
Down Pipe (2 metres)	1	______	4.39	4.39
Total Cost			£20.34	

Figure 16: Breakdown of Component Cost for Prototype

The design was simplified as much as possible to reduce the components required in order to cut down on cost. The product generates very low power, as such it was necessary for it to be low cost so that not to deter potential buyers. Our total cost of components dominates the cost of producing the prototype at £20.34. It is possible to set a price that covers that cost without it being cost prohibitive. A potential market is available for our product evident by the results of our survey. This indicated that the majority of people are interested in cutting their energy bill and going “green” with 67.24% and 58.33% of responses showing high level of interest respectively.

Conclusion

The world’s energy crisis has become increasingly prominent in recent years. In addition to the reserves of fossil fuels becoming depleted, their harmful effects on the environment mean that the world must eventually use only clean, renewable sources of energy to sustain itself.

HydroGen is a product which is in sync with this philosophy, harnessing the energy of rainwater which is normally wasted to generate a small amount of clean, renewable electricity which can then be used in low powered devices. Apart from being environmentally friendly, the product is also low maintenance and efficient. These features make it desirable for people who live in countries with high rainfall. Additionally, a survey conducted by the group provided a strong indication that the product could be made economically viable if further developed.

The concept design of the product developed at each stage of the project. In order to ensure that the ultimate goal did not change, the group selected ten important product design specifications (PDS), as the concept developed. In this way, the initial PDSs also helped limit the scope of the project.

Future Work

What are the next steps?

The current mechanism relies on converting gravitational potential energy into kinetic energy into electric energy. Due to the product’s relatively low turnover, it was decided that the primary application of the product is to charge batteries. The dynamo generates the electricity which then in turn charges rechargeable alkaline batteries.

Taking into consideration the scenario and the optimum conditions at which our product will work best, it seems this could be an issue when it comes to real life applications. For example, a potential use of our system could be to power an external burglary alarm system or to even power exterior lights of a household. However one could question the functionality and use of the system during counteracting conditions such as when there is minimum or even no rainfall for a long period of time.

To overcome this, a backup system could be designed such as integrating small solar panels that charge the same battery. Hence during times where there is no rainfall but relatively high sunlight exposure, the system still functions effectively and significantly reducing the chance of system downtime or failure.

Solar powered burglar alarms[16] and security systems already exist in the market as shown in the link below. Despite our product's key mechanism being fundamentally different, such systems that already exist in the market can be easily integrated with our product increasing the boundaries of the market segments that our product can be served to.

What would you have done if you'd had more time?

Due to the time sensitive nature of the assignment, it was necessary to scale back the scope of our original project idea to make it more manageable. Given more time, some changes would have been made to the final design. In the future, a filter would have been implemented that would prevent the detritus associated with indoor plumbing from clogging up the water wheel. Using such a filter, the system could be kept indoors where there is a steadier stream of water - as a result, more energy to be converted. The potential increase in power output however, is not the only benefit associated with an indoor system. The power output will also fluctuate less as it is no longer dependent on the weather. In addition, ways of alerting the user as to when the battery is fully charged would have been developed. In this way, the system is as convenient and easy to use as possible is assured. Furthermore, the possibility of linking the system to an app able to allow the user to keep track of the power output of the system would provide vital information to the user. Finally, with more time the various wheels of different size and shapes would have been tested. The efficiency of any wheel is affected by the flow conditions therefore, different wheels could have a significant effect on the overall efficiency. These changes would have helped to make the product more practical and marketable.

[16] "Solar Powered Burglar Alarm and Security Systems." *Easy Alarms*. N.p., n.d. Web. 14 Mar. 2015. http://www.easyalarms.co.uk/solar_powered_burglar_alarm_systems.asp

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Appendix

Proposal

Electricity Production from Waste Water

***Abstract*—Energy is lost down the drain. Instead it should be harvested to power appliances around the house, cutting down waste and paving a greener future.**

A large amount of water is expelled each day from sinks, toilets, tubs and so forth. Waste water flowing through pipes contains kinetic energy which presently is completely lost. By placing a mechanism within pipes this kinetic energy could be converted into electricity, making it useful again. Users would benefit from reduced bills and a greener environment. To make the technology widely usable, it will be designed to integrate with existing plumbing without requiring significant changes.

Feasibility study

IT is important to determine if a realistic solution exists to harness and store the energy lost in waste water flow through pipes. The amount of energy must be large enough to power appliances around the house. The capturing mechanism must be durable under fluids as well as lightweight and sized to incorporate with existing plumbing. The storage device must dispense energy in substantial amounts and retain it till required. Additionally, both devices will need to be cost viable.

For the product to be profitable it is essential to determine a market for it by demonstrating people show interest in employing such a technology in their homes.

What needs to be solved?

To capture energy a generator needs to be found that will efficiently convert the water's kinetic energy into electrical energy for use around the house. As water flow will vary throughout the day a stabilising system will need to ensure even and sufficient flow across the generator.

Before the generator a filter system will have to be designed and employed to prevent debris from destroying machinery and reducing conversion efficiency.

Finally a storage device, such as a battery, to store and dispense the converted energy is required. The battery must allow mains to take over when it is unable to supply electricity to appliances.

What research needs to be done?

A suitable generator needs to found that will both fit into plumbing and convert appreciable amounts of energy while being inexpensive. This product's success depends greatly on its low cost and adaptability to household plumbing without demanding much change.

A viable storage mechanism also needs to be identified and perhaps modified to fulfill the brief. To maximize output optimum filter dimensions, mechanism materials, water flow rate, pipe diameter, and battery type need to be thoroughly researched and accurately identified.

What expertise is needed?

Knowledge of power engineering and energy conversions will be extremely helpful in perfecting the generator and battery for this product. Familiarity with basic fluid mechanics will assist in design development and recognizing optimum conditions to achieve maximum conversion efficiency. Finally, an understanding of analogue electronics will be beneficial in compiling all the parts into a functional product.

Some Additional Information

The long term plan

Eventually a similar product can be developed for the supply portion of water pipes. At this moment focus is given on waste water as it doesn't disrupt the supply stream or major water distributers, avoiding expensive repercussions.

Extensive testing will also be required to pass the solution as worthy of installation in homes. To increase user-

Format based on IEEE Transaction conventions.

friendliness an app can be developed to monitor live data of water being spent, energy being harvested, savings being made and so on. Data should work as an incentive for users to repeat purchase and save energy.

Calculations

"According to the Environment Agency the national water use average is 163 litres per day" [1]. Multiply this number by 4 to estimate the average household water usage as 652 litres per day. Almost 80% of this ends up flowing down a drain pipe. That is 652 * 0.8 = 521.6 litres per day being completely wasted.

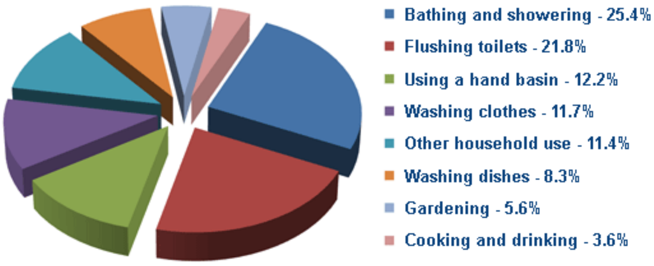


Fig. 1. Pie chart illustrating average percentages of daily water consumption and consequently water wastage

Furthermore the high flow rate of this waste water, which will turn the generator, can reach as high as "25.2 litres/second in a 3 inch pipe" [2].

By creating this product kinetic energy found in flowing water will no longer be wasted, rather converted into electricity to power homes in a clean and green manner.

References

[1] Affinity Water Limited. (n.d.) *How much water do you use?* [Online] Available from: https:// affinitywater.co.uk/ [Accessed 11th October 2014].

[2] The Engineering ToolBox. (n.d.) *Waste Water and Flow Capacity*. [Online] Available from: http://engineeringtoolbox.com/ [Accessed 11th October 2014].

Meeting Minutes

EE2 Project

Meeting Minutes

Start Time : 3:00

Finish Time: 4:14

February 27, 2015

Present: Sav, Waris, Alia, Nouman, Sid, Will, Tomison

Next Meeting:4 March Wed (Tentative)

Tasks Assigned

Intro and background of the report – Waris Ameen

Research and Evidence- testing, selecting, designing – Sav and Will

Further Development- External links to other Topics – Sav

Technical- Not Assigned

Analysis and Understanding (improvements suggestions) – Not Assigned

Evaluation (Management) – Alia

Socio Economic Impact of our project– Nouman

User requirements and Survey – Tomison

Research on Competitors in the Market and how to set our product apart. Marketing strategies – Sid

Prototype- Not Assigned

Deadline for this task- Monday, 15:59:54

Tasks without a specified deadline

Website Development- Sid

Information on ABOUT US PAGE- EVERYONE

EE2 Project

Meeting Minutes

Start Time: 5:00

Finish Time: 7:00

March 5, 2015

Present: Sav, Waris, Alia, Nouman, Sid, Will, Tomison

Next Meeting: Not Decided

Tasks Assigned

Separate tasks according to the structure of the report were assigned to team members. The breakdown is given below:

Report Structure:

The report should include the following sections:

1. Cover page (ALIA)

- Include a cover page with your group number, title of the project, supervisor's name, names of the group members (with CID), the date of submission and "Imperial College"

- Not included in the total page count

2. Contents page

- Not included in the total page count

3. Abstract (WILL)

- Not included in the total page count

4. Introduction / Background: (WARIS)

- The information in this section helps put the report in context

- A recap of the Interim Report. Description of area / problem that the group is addressing (no more than 1 side of A4)

5. Design Criteria:

- Highlight the most important elements of the PDS for your project (maximum of 10 out of the 32 elements available); these will constitute your design criteria.

- Only include your PDS in the Appendix if it has changed since the Interim Report.

6. Concept Designs considered: (ALIA)

- Brief description of the concepts (three?) considered. **One picture and a paragraph's description should suffice.**

7. Concept Selection:

- Use one of the matrix methods and provide the rationale for your choice **(NOUMAN)**

8. Concept development: (Nouman, Waris, Sav)

- Please refer to the following sections in the marking scheme:

c. Analysis and Understanding

d. Originality

e. Technical aspects

- Provide sketches, feasibility, estimated cost or any other relevant information. Explain how the system / concept operates and fulfils the design criteria.

- Sketches of the circuit, waterwheel and in depth analysis **(WARIS)**
- Estimated cost
- Power generation stats
- Testing **(WILL TOMISIN AND SID)**
    - Average speed of water entering pipe (Flow rate) Theoretical data such as flow rate of water could be gathered online. Analyse similar systems such as rain water harvesting and storage method. **(SAV)** (rpm, torque and estimation of power generated)
    - Assumption of using a fixed amount of water entering the pipe. (Theoretical system) **SID**

Introduction

9. Discussion: (Nouman, Waris, Sav)

- See c., d. and e. above

10. Conclusion and Future Work:

- What are the next steps? **Sav**

- What would you have done if you'd had more time? **Tomisin**

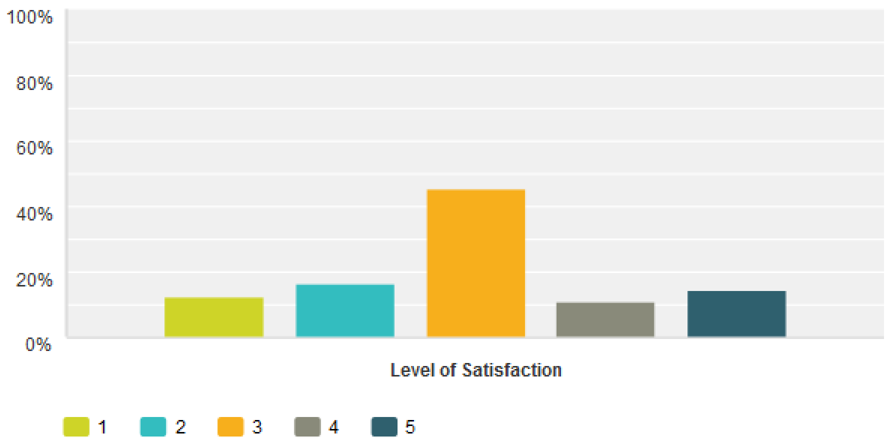
-Conclusion **Tomisin**

Deadline for this task- 14th March, 16:00

Survey

How satisfied are you with your current energy bill?

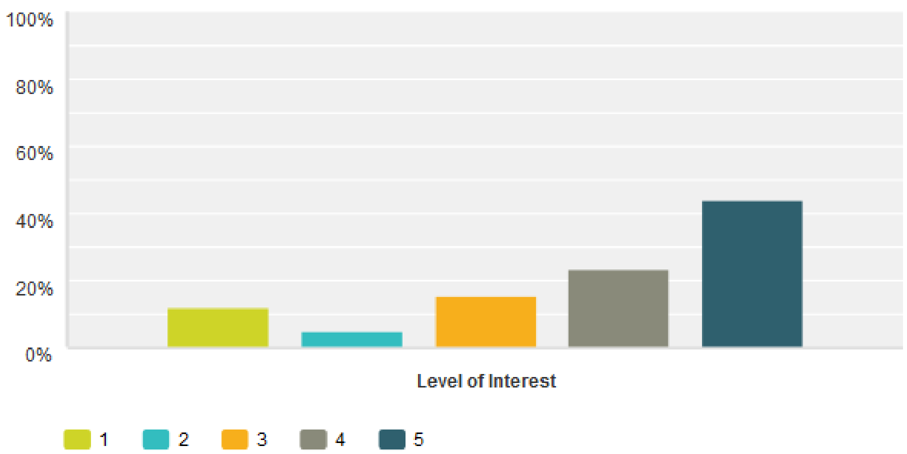
Answered: 55 Skipped: 7



	1	2	3	4	5	Total	Weighted Average
Level of Satisfaction	12.73% 7	16.36% 9	45.45% 25	10.91% 6	14.55% 8	55	1.00

How interested are you in finding ways to reduce your energy bill?

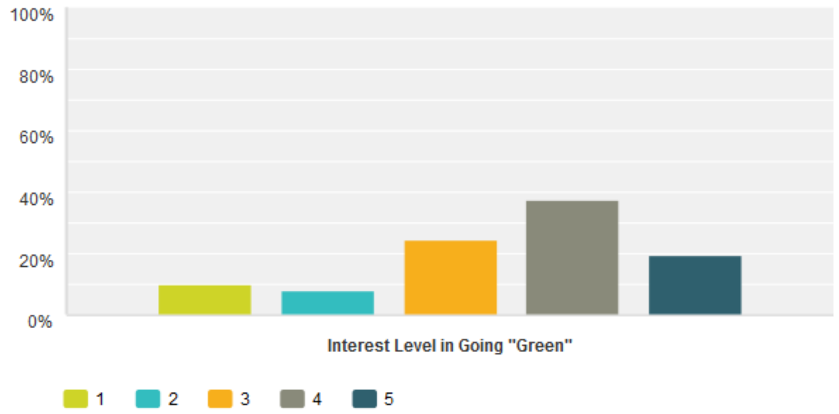
Answered: 59 Skipped: 3



	1	2	3	4	5	Total	Weighted Average
Level of Interest	11.86% 7	5.08% 3	15.25% 9	23.73% 14	44.07% 26	59	1.00

How interested are you in going “green”?

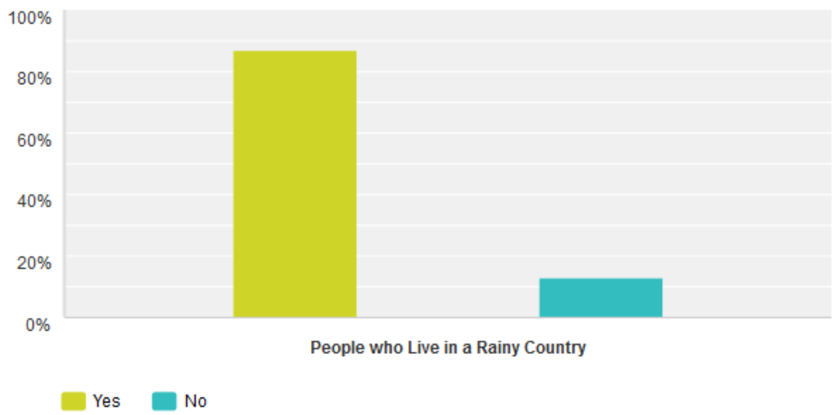
Answered: 61   Skipped: 1



	1	2	3	4	5	Total	Weighted Average
Interest Level in Going "Green"	9.84% 6	8.20% 5	24.59% 15	37.70% 23	19.67% 12	61	1.00

Number of People who Live in a Rainy Country

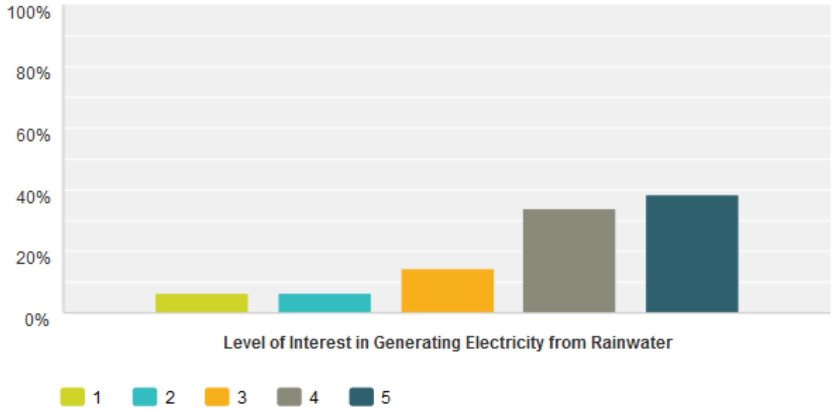
Answered: 62   Skipped: 0



	Yes	No	Total	Weighted Average
People who Live in a Rainy Country	87.10% 54	12.90% 8	62	1.00

Would you be interested in a product that generates energy from rain water?

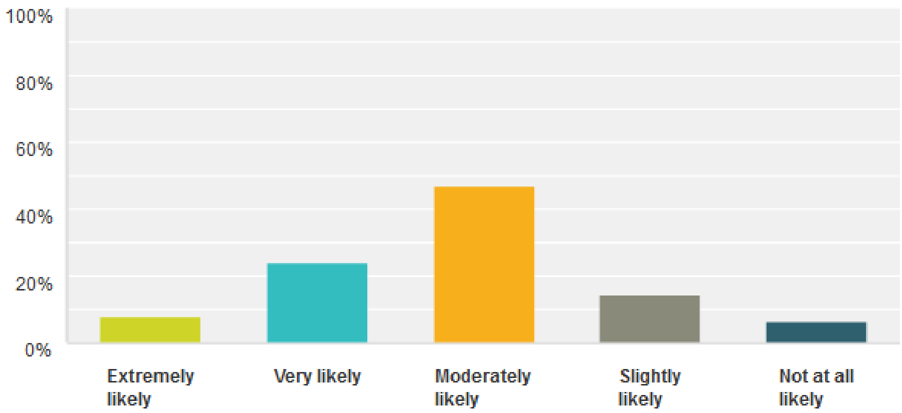
Answered: 62 Skipped: 0



	1	2	3	4	5	Total	Weighted Average
Level of Interest in Generating Electricity from Rainwater	6.45% 4	6.45% 4	14.52% 9	33.87% 21	38.71% 24	62	1.00

If this product were available today, how likely would you be to buy this product?

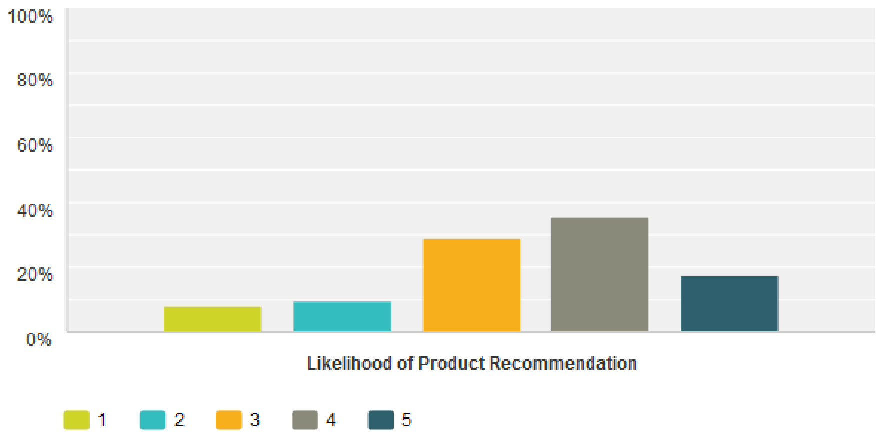
Answered: 62 Skipped: 0



Answer Choices	Responses	
Extremely likely	8.06%	5
Very likely	24.19%	15
Moderately likely	46.77%	29
Slightly likely	14.52%	9
Not at all likely	6.45%	4
Total		62

How likely is it that you would recommend our new product to a friend or colleague?

Answered: 62 Skipped: 0



	1	2	3	4	5	Total	Weighted Average
Likelihood of Product Recommendation	8.06% 5	9.68% 6	29.03% 18	35.48% 22	17.74% 11	62	1.00