WAP

(Wireless Agricultural Powering)

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Cleaner, inexpensive and eco-friendly energy from

Plant- Microbial Fuel Cell

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Abstract:

Once an exporter of oil and gas, Egypt is now struggling to meet its own needs. The growth in energy consumption is a response to the country's economic expansion, industrialization, and change in people's life style. Although all energy forms have been subjected to high growth, electricity consumption has increased substantially causing serious concerns over the power sector's fuel mix, heavier reliance on fuel oil, and an unaffordable burden on the government budget. As a result, the government is determined to diversify the energy mix and to improve the efficiency of electricity consumption. It has also recognized that energy diversification and efficiency can impart other benefits such as cleaner environment, transfer of advanced technologies, and possible new areas of manufacturing and services. So the solution for this problem must be efficient, economic, sustainable and eco-friendly to overcome most of the troubles facing Egypt in this field. "Plant microbial fuel cell" is believed to be the ideal solution for the energy issue that can fit the previously mentioned requirements so we develop the anode and the cathode in the MFC and we found new material for making the proton exchange membrane which is "Nylon" so we made prototype for this idea and to make test plan on it to know its efficiency and its cost. And we get better results than we expected.

Introduction:

Since the last 50 years till this moment we are suffering from the energy crisis, electricity blackouts, pollution that results from the burning fossil fuel; Egypt depends on non-renewable source of energy which is the fossil fuel that is neither clean nor cheap. Egypt consumes a huge amount of energy in different fields and these consumptions are not coherent with the production. The continuous increment of consuming fossil fuel is not strange because we ignore renewable sources of energy such as solar cell, wind turbines, geothermal, biomass, Etc…. As a result we had to find source of energy instead of the fossil fuel in order to get rid from the energy crisis, pollution and greenhouse gases, which are the main reason for global warming phenomenon. In order to find solution for this problem we investigated the prior solutions in this field. From these solutions project namely (microbial fuel cell) that gave us the opportunity of thinking about the idea of

P-MFC (plant-microbial fuel cell) that mainly depends on making the plant its photosynthesis process with the equation $6CO_2 + 6H_2O$ –sun light----> $C_6H_{12}O_6 + 6O_2$ producing glucose ($C_6H_{12}O_6$). The plant consumes 30% of glucose and stores the 70% in the soil of the plant to be eaten by microorganisms naturally living in the soil of the plant like Shewanella and Geobacter. These microorganisms produces protons H^+ and electrons e^-. In our P-MFC it is separated into two parts one for the soil and it contains the anode (made of Aluminum) to attract electrons produced from the microorganisms and the other half contains the cathode (made of copper). There is PEM (proton exchange membrane between them to let the protons H^+ pass to the cathode while the electrons don't pass because the plant we already use in the project is a watery plant needs more water to grow (rice soil) so it prevents the electrons e^- from reacting with the oxygen O_2 in the atmosphere. Otherwise it go in the circuit from anode to cathode.

Review of literature:

Like Microbial Fuel Cell (MFC), Plant Microbial Fuel Cell (P-MFC) was made in tubular system (Logan.2006), (Helder, 2012). And this system reduces the efficiency of (P-MFC) and increase the internal resistance of it according to (Plant-e, 2013). But we will use better system to overcome these problems which is the flat system. the materials which was used as Proton Exchange Membrane (PEM) may be Nafion or Teflon. Nafion has very low efficiency relative to its high cost (e.g. Nafion). On the other hand, Teflon is inexpensive but has very low efficiency. In our working, we discover new material which was Nylon that is considered the best choice.

Materials & Methods:

Materials	
Glass Container (25cm*25cm*20cm)	
Copper plate as Cathode	
Aluminum plate as Anode	
Nylon as Proton Exchange Membrane (PEM) (25cm*20cm) from roll	
Crocodile wires	
Green plant (Rice or Sugarcane or Alfalfa)	 Sugarcane

Multimeter	
pH Meter	
calcium carbonate (30 g)	

Methods
1- Putting the wet plant (Sugarcane) with its soil inside the glass container
2- Making space between the soil and the wall of the glass container around 2cm to 2.5cm and Watering the plant with water
3- Putting the membrane (Nylon) in the end of the soil
4- Immersing the Anode (Aluminum) in the soil and touching it with the root of the plant
5- Putting the cathode in the container behind the proton exchange membrane.
6- Connecting the anode and the cathode plates with crocodile wires.
7- Using Calcium Carbonate and pH meter to make the pH reading from the membrane to 10cm in the direction of the soil between 7 to 7.3 and the pH reading in the rest of the soil from 6.7 to 7.
***Remember to expose the plant to sunlight.**

Design Requirements & Testing	steps
Efficiency	1) Record the readings of the multimeter to determine the potential difference in our flat-plate system design. 2) Compare between the efficiency of MFC and P-MFC. 3) And comparing between the nylon membrane and the gelatin Membrane.
Cost	We compared between the cost of the standard microbial fuel cell and our P-MFC concerning the efficiency.

Results:

- **efficiency test plan results**

  Voltage = 1.4 V (±3%) (per 25cm*25cm)

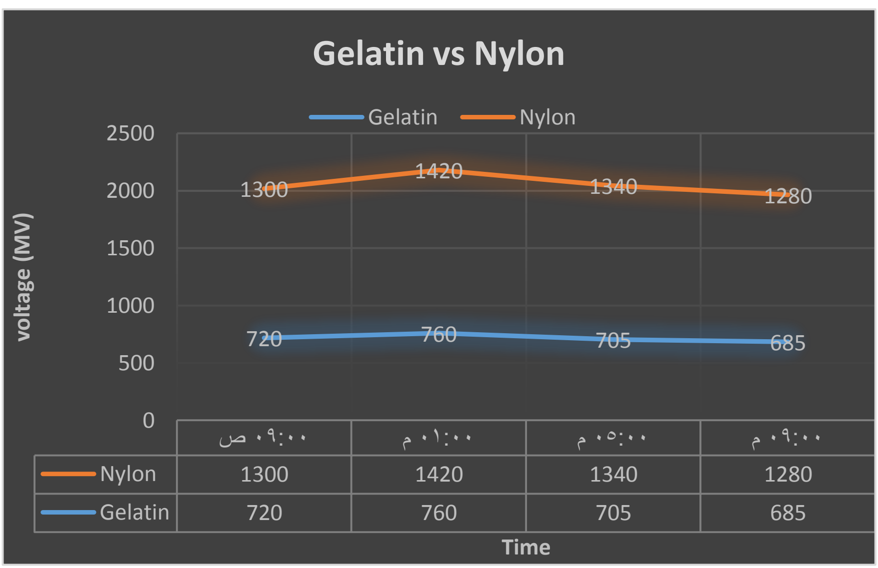
  Current intensity = 1.6 A (±3%) (Per 25cm*25cm)

  Power intensity(per25Cm*25Cm) = voltage *Ampere =

  = 1.4 * 1.6 =2.24 watt

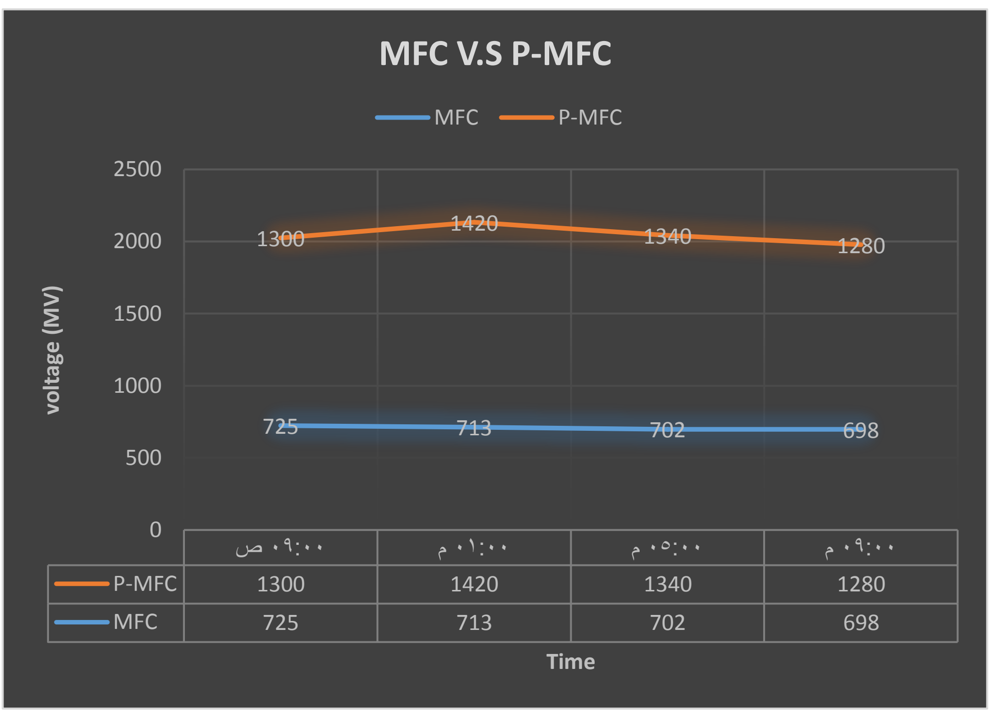
We tested two types of proton exchange membrane (PEM): (Nylon) and (Gelatin). We recorded the voltage of the P-MFC using these new (PEM) over 4 times a day. And the results were:

Time	Gelatin	Naylon
9 AM	720 MV(± 3%)	1300 MV(±3%)
1 PM	760 MV(± 3%)	1420 MV(±3%)
5 PM	705 MV(± 3%)	1340 MV(±3%)
9 PM	685 MV(± 3%)	1280 MV(±3%)



After that, we compared between the Plant-Microbial Fuel Cell (P-MFC) and traditional Microbial Fuel Cell(MFC) and the results were:

Time	MFC	P-MFC
9 AM	725 MV	1300 MV
1 PM	713 MV	1420 MV
5 PM	702 MV	1340 MV
9 PM	698 MV	1280 MV



➢ Cost test results

We compared between the cost of (MFC) and the cost of (p-MFC) and the results were:

Material	in MFC (average cost)	In P-MFC (average cost)
Proton exchange membrane	Nafion (150 $)	Nylon (0.165$)
Anode	Graphite (2$)	Aluminum (0.5$)
Cathode	Graphite (2$)	Copper (0.5 $)
Total	154 $	1.165 $

Discussion:

➢ The plant & soil

The plant is the main part in our project because it is the source of organic matter. So we chose rice (in the summer) and alfalfa (in the winter) to make the integration between the agricultural seasons. We think that the rice and the alfalfa are suitable plant to use in our project because they have high photosynthetic efficiency and the properties of their soil which are:

- Having Good water retention capacity.
- Having Good amount of clay and organic matter.

We need the first property (Having Good water retention capacity) because we need the Existence of the water in anodic half to prevent the electron from combining with the molecules of Oxygen (O_2) from the air. We also need the second property (Having Good amount of clay and organic matter) because the organic matter is the nutrient of bacteria.

Additional to these properties, the soil of these plants has suitable environment for the living of microorganisms like Shewanella and Geobacter.

As we research for similar plant which is planted in the same environment and has the same properties of rice and alfalfa, we found the sugarcane.

Sugar cane is the source of sugar in all tropical and subtropical countries of the world. We can use sugarcane in all seasons because it is planted all over the year. Sugarcane also has the highest photosynthetic efficiency (from 7% to 8%). So it would be the best choice to use in our prototype.

- **The electrodes**

Plant microbial fuel cell (P-MFC) consists of two parts that have been separated by the proton exchange membrane (made from Nylon).Each part of P-MFC contains one electrode in the soil there is the anode electrode (made of Aluminum) and the other half contains the cathode electrode (made of copper).

Importance of the electrodes in (P-MFC):

- The anode (Aluminum):
  The electrons produced from bacteria are attracted to be transferred to the cathode through the circuit. The anode is buried deep enough, where there is no oxygen, so this reaction (between electron and oxygen) could not take place right next to the anode.

  We chose aluminum as anode because it is very high conductor of electricity, having low corrosion rate, its life time is longer than other electrodes and has high voltage.

- The cathode (Copper):
  It completes the circuit with anode to let the passage of the electrons flow through the wire. Electrons from the anode travel up a wire to the cathode and, once there, they react with oxygen (from the air) and hydrogen (produced by the bacteria as it digests the nutrients in the soil) to create water.
  We chose copper because it is good conductor of electricity, It is cheaper than other electrodes (like graphite), has higher surface area.

Proton Exchange Membrane (PEM)

Proton Exchange Membrane is a semipermeable membrane that designed to allow proton penetration from anodic half to the cathode and prevent the water and the electrons penetration. But why we need to prevent water penetration?

Because we need the Existence of the water in anodic half to prevent the electron from combining with the molecules of Oxygen (O_2) from the air. In traditional Microbial Fuel Cell (MFC), fluoropolymer Perfluorosulfonic acid -with trade name Nafion- is used as (PEM) but it has low efficiency relative to its price which is around 150$ and it isn't available in Egypt. So we tried to find for alternative (PEM) which achieve our design requirement –low cost and high efficiency- .

We found Gelatin powders which used in the food. We did the test plan on it and we found that it has quite good but it has very low thermal stability it means that it melts in room temperature (25 °C) after 4 hours to form jelly material we try to solve this problem by adding some salt and try it again and we found some improvements but it also melts after few hours. We also found another material which is Nylon ($C_{12}H_{22}N_2O_2$). Nylon is waterproof material formed from a polymer of adipic acid and hexymethylene diammine. It is widespread material as it used in several fields. We did the test plan on it and we found that it has high thermal stability. It also has high efficiency additional to its low cost. It is only .2$.

pH in the soil

Firstly, pH is a numeric scale used to specify the acidity or basicity of a soil. More Existence of proton (H^+) for example more acidity means low pH and vice versa for calculating the PH (PH formula):

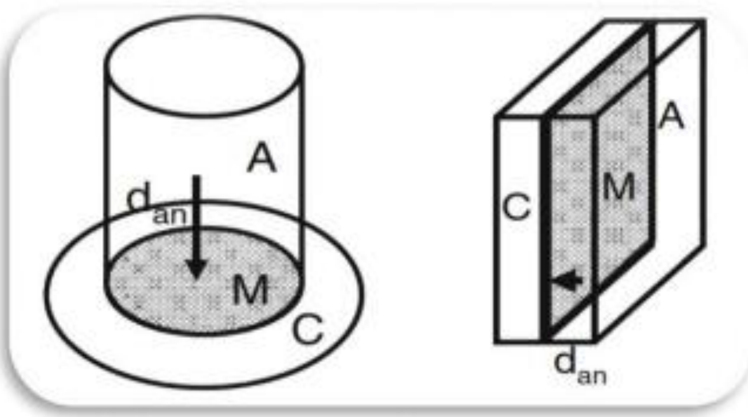
$$pH = -\log[H+]$$

Or with pH meter.
The neutral pH rate in the soil is from 6.6 to 7.3. As we know, we need the proton (H^+) to diffuse from anodic half to cathodic half so we need to make the pH rate of cathodic half higher than the pH rate in anodic half to make the proton (H^+) diffuse from an area of high proton concentration (low pH rate) to an area of lower proton concentration (high pH rate). So we used Calcium Carbonate ($CaCO_3$) to make the pH rate in cathodic half from 7 to 7.3 and the pH rate in anodic half from 6.6 to 6.9.

- **prototype system**

In order to achieve the highest efficiency for our plant-microbial fuel cell we have to choose the best system design to build our plant microbial fuel cell according to it. There are two different systems (tubular system & flat plate system) each one plays an important role for increasing and reducing the internal resistance (diffusion of the ions in the plant microbial fuel cell from the anode to the cathode) inside the plant-microbial fuel cell.

- Tubular system:
  The internal resistance in this system is very high. There is long distance between the anode and the cathode (A long distance from anode to cathode leads to transport losses in the anode) of the plant microbial fuel cell.
- Flat-plate system:
  Since the membrane in the flat-plate design is placed vertically, membrane surface area per geometric planting area is increased, which allows for lower internal resistances. From the advantages of the flat- plate system is that the distance between the anode and the cathode is shorter than the one in the tubular system.



Tubular system & flat system

So in order to increase the output of the P-MFC, the internal resistances need to be reduced and this will be found in the flat- plate system so we choose this system to build our prototype according to it.

- **Mediator-less P-MFC**

One of the features in the plant microbial fuel cell that makes it different from the traditional microbial fuel cell is that the P-MFC is mediator-less unlike the traditional MFC that depends on specific mediators or electrolytes to facilitate the pass of electrons to the anode like the potassium hydroxide, potassium chloride, sodium hydroxide, sodium nitrate.

Reason for being the P-MFC mediator-less:

1. It does not depend on electrolytes (such as potassium hydroxide) because they are toxic substance that may harm the plant and have bad influence on the plant
2. Electrolytes have bad influence on the electrogenic microorganisms which are the bacteria that produce the electrons(e-) and protons (H+) like shewanella and geobacter.

The alternative of the mediators and electrolytes in the plant microbial fuel cell (P-MFC)

- There are electrogenic bacteria naturally found in the soil of the plant. These electrogenic microorganisms have the ability to breathe metals and produce sticky substance that facilitate the electron pass to the anode. These sticky substances collected around the anode making layer called “biofilm”.

- **Microorganism (Bacteria)**

They are electrogenic microorganisms that are naturally being found in the soil, also they are found in anaerobic environments such as sediments of rivers, lakes or seas. These creatures have the ability of producing electrons and protons when they breathe the metals.

Since we will put Aluminum as anode (bacteria will create a biofilm on it) in the soil the bacteria will have the ability of producing protons (H^+) and electrons (e^-).

Types of electro-genic bacteria:

1. Shewanella
2. Geobacter

- **Our centralized project**

We looked forward to making an integration system to manage our grid. The first problem that we faced was the transmission of the output energy from the cell to battery.

Firstly, we thought on the traditional wires, but we faced many problems such as:

1- In the grid, there are several kinds of huge vehicles which are used to help the farmer in the watering the farm or using to plow the farm.
2- It will also make the transporting of farmer in his farm more difficult.
3- It must be replaced annually.

After these problems we had to research for alternative way. We found the wireless electricity which is considered to be the best way to transport the output energy of

P-MFC. Wireless Power includes Inductive Power Transfer (IPT), Inductive Coupling and Resonant Power Transfer. Each these terms essentially describe the same fundamental process. The transmission of energy from a power source to an electrical load, without connectors, across an air gap. The basis of a wireless power system involves essentially two coils. A transmitter and receiver coil. The transmitter coil is energized by alternating current to generate a magnetic field, which in turn induces a current in the receiver coil.

Conclusion:

Modifying the plant microbial fuel cell with effective changes on it that increases its efficiency and noticeably reduce its cost instead of being expensive. Using very cheap and high efficient materials and this led the plant microbial fuel cell to meet its design requirements. Plant microbial fuel cell is an easy project to be applied in the agricultural field and it will be good resource of electricity to the developing country.

The following calculations for the output from plant microbial fuel cell (P-MFC) and what this project will provide Egypt with if it is applied.

Voltage = 1.4 V (±3%)

Current intensity = 1.6 A (±3%)

Power intensity (per 25 Cm *25 Cm) = voltage *Ampere

= 1.4 * 1.6 =2.24 W per 25Cm*25Cm

Power intensity per M2 = 2.24 * 16 = 35.9 W / M2

We have 4200.83 M2 in one acre

Power intensity in one acre = 35.9 * 4200.8 = 150808.7 W/acre

Power in K.W.H produced in one day from one acre = $\frac{\mathbf{150808.7 * 86400}}{\mathbf{3.6 * 10^{\wedge}6}}$ = 3619.5 K.W.H

- Sugarcane acres:
  - We have 350000 acre of sugarcane in Egypt

Then the produced power from these acres in one day =

3619.5 * 350000=1266825000 K.W.H

=1266.9 G.W.H

- Rice acres

We 2350000 acres.

- The produced K.W.H from one acre in one day = 3619.5 K.W.H
- Produced K.W.H from the acres of rice in one day =

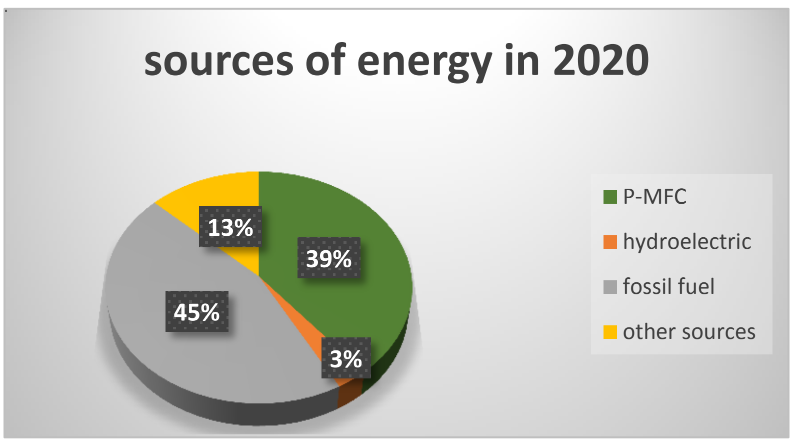
3619.5 * 2350000 = 8505825000 K.W.H =8506 G.W.H

- Since rice is planted 6 months in year so we will plant wheat as alternative for rice the rest 6 months of the year.

The produced G.W.H from the rice acres and sugarcane acres =

8506 + 1266.9 = 9772.9 G.W.H (PRODUCED IN ONE DAY)

- Since Egypt consumes 25000 G.W.H (In one day)
- So we will produce 39% of the consumed G.W.H in Egypt



From the best modification on the plant microbial fuel cell and it will make this project distinctive is the transferring of the electricity from the plant microbial fuel cell in the agricultural field to the storage batteries with wireless technique. It will be dangerous if the electricity transferred through wires as there is water in the soil and in the cathodic half.

Recommendations:

We recommended for the following things in order to follow it in the future to develop the plant microbial fuel cell:

1- Using the monolayers of Graphene and Hexagonal boron nitride as a proton exchange membrane (PEM) to increase the efficiency of microbial fuel cell and decrease the

Cross-over of protons. We didn't use it because it needs hard conditions to manufacture.

2- Constructing an automatic system to control and regulate the PH in both halves of the cell through automatic injection of Calcium Carbonate.

3- Using (lead acid battery) in the storage of the energy produced because of its low resistance and it lasts for long time which will perfect for storage of energy in the grid.

References:

- **Journals**

- Helder et al. Biotechnology for Biofuels 2012, 5:70 www.biotechnologyforbiofuels.com/content/5/1/70

- **Web sites**

- P., & Quick, D. (n.d.). Plant-Microbial Fuel Cell generates electricity from living plants. Retrieved April 21, 2016, from http://www.gizmag.com/plant-microbial-fuel-cell/25163/
- Biotechnology for Biofuels. (n.d.). Retrieved April 21, 2016, from https://biotechnologyforbiofuels.biomedcentral.com/articles/10.1186/1754-6834-5-70

- Bruce Logan Research - Microbial Fuel Cells. (n.d.). Retrieved April 21, 2016, from http://www.engr.psu.edu/ce/enve/logan/bioenergy/research_mfc.htm

- A review on the role of proton exchange membrane on the performance of microbial fuel cell. (n.d.). Retrieved April 19, 2016, from http://onlinelibrary.wiley.com/doi/10.1002/pat.3383/full

- Beer, C. D., Barendse, P., & Khan, A. (2012). Emulation of high temperature PEM fuel cell electrical dynamics and operational phenomena. 2012 IEEE Energy Conversion Congress and Exposition (ECCE). doi:10.1109/ecce.2012.6342216

- Hosseinpour, M., Vossoughi, M., & Alemzadeh, I. (n.d.). An efficient approach to cathode operational parameters optimization for microbial fuel cell using response surface methodology. Retrieved April 17, 2016, from http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3937156/

    - S. J. (n.d.). Illumin - Microbial Fuel Cells: Generating Power from Waste. Retrieved March 21, 2016, from http://illumin.usc.edu/134/microbial-fuel-cells-generating-power-from-waste/

    - Treacy, M. (n.d.). Plant-Microbial Fuel Cell Produces Power from Plants. Retrieved April 21, 2016, from http://www.treehugger.com/clean-technology/plant-microbial-fuel-cell-produces-power-plants.html

    - Plant-e.com Home. (n.d.). Retrieved March 8, 2015, from http://plant-e.com/
    - Energy.gov. (n.d.). Retrieved March 15, 2015, from http://energy.gov/eere/fuelcells/fuelcells

- How Wireless Power Works. (2007). Retrieved July 19, 2016, from http://electronics.howstuffworks.com/everyday-tech/wireless-power.htm
- Wireless Charging & How Inductive Chargers Work • PowerbyProxi. (n.d.). Retrieved July 19, 2016, from http://powerbyproxi.com/wireless-charging/

- **Books**

- Reece, J., & Urry, L. (n.d.). Campbell biology (Tenth ed.).
- Kelter, P., & Zumdahl, S. (2007). Chemistry, seventh edition, Zumdahl. Boston: Houghton Mifflin.