The Bloom Box:
An Investigation into the Bloom Box Fuel Cell

An Interactive Qualifying Project Report
Submitted to the Faculty
of the
WORCESTER POLYTECHNIC INSTITUTE

In partial fulfillment of the requirements for the
Degree of Bachelor of Science

By Brian Goodman, Nick Bosowski, and Thane Sanford

____________________ ____________________ ____________________

Adviser: Professor Robert W. Thompson

____
Date: March __th, 2011

Abstract

The primary purpose of this report is to examine the technical implications of the Bloom Box fuel cell. Secondly the report evaluates the Bloom Box as a potential electricity source for homes and private businesses based on the economic advantage that it may provide. It also compares the Bloom Box to other off grid electricity options. Lastly, based on the compiled data, the report provides a group opinion of the Bloom Box's potential.

Table of Contents

Introduction

In today's expanding global economy, the need for sustainable energy is more pressing than ever. In 2009 over 75% of the electricity used in the United States came from non-renewable fossil fuels.

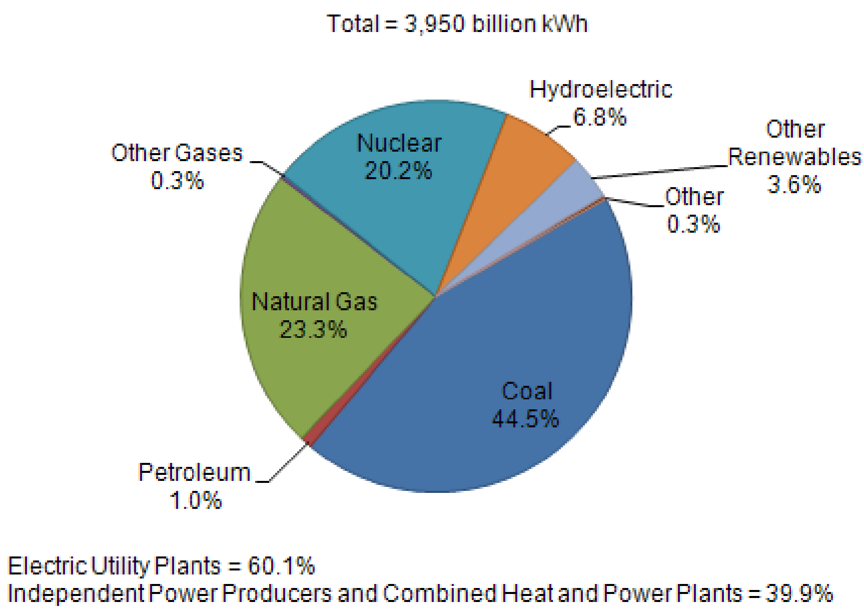


Figure 1 US energy consumption by fuel ("Eia- electricity data,," 2010)

There are many concerns over electricity's current dependence on fossil fuels for production. First, the use of fossil fuels in electricity production releases a lot of potentially harmful emissions such as CO_2 and other greenhouse gases into the air. Many scientists theorize that excess CO_2 in the atmosphere is causing an increase in global temperatures, which will have a negative effect on the environment. Others suggest that this is a result of natural processes and that global warming is not something to be concerned about. Regardless of the truth in this matter, reductions in CO_2 emissions would not have a negative impact on climate, and thus it is felt that exploration into alternative energy sources which do not rely on hydrocarbon combustion is something worth pursuing. Sustainability is the next major problem with using fossil fuels to produce electricity. Estimates of the amount of time that these fuels can sustain our needs vary, but regardless the dependence on them is a problem as they will inevitably run out. In a pessimistic outlook on our ability to use these fuels, their availability could diminish greatly in coming years. In more optimistic views the price of these fuels will continue to rise as the end of their supply draws nearer, making them less affordable for use. New sustainable energies should be looked at as possible solutions to this crisis as they can be used to either help alleviate the usage of fossil fuels or eventually replace them completely.

Means of replacing these fossil fuels are not necessarily crucial for the near future, as world coal reserves will not like expire for about 250 years at the current rate of usage (Nersesian, 2007, p. 89).

. Oil is expected to last 40 years at its current rate of usage (Nersesian, 2007, p. 90). Prices for fossil fuels will increase as demand rises and reserves fall, making them an expensive commodity. Oil is complicated by the fact that about half the oil under the Earth's surface is currently irretrievable (Nersesian, 2007, p. 196). Regardless of the exact numbers, it is likely that this century will end with oil no longer being available (Nersesian, 2007, p. 202). One reason technologies such as the Bloom Box may be useful in a transition to completely renewable sources is that the reservoir recovery rate, the amount of material recoverable from a given deposit, of natural gas, which the Bloom Box typically runs on, is 70-80% compared to the expected 30-40% recovery rate of oil[2]. This means that if equivalent amounts of new natural gas and oil were found underground, about twice as much natural gas would be recovered as the oil. A typical natural gas plant runs at about 35-40% efficiency (Nersesian, 2007, p. 248), compared to the 50% efficiency advertised by Bloom Energy Corporation("Es-5000 energy server," 2010).

The purpose of this report is to outline the technology of Solid Oxide Fuel Cells (SOFC), examine the potential developments made by Bloom Energy, compare the Bloom Box to other SOFCs as well as competing sustainable energy technologies, analyze the advantages and disadvantages of the Bloom Box, and ultimately determine whether the Bloom Box can compete with other green technologies.

One question to consider when discussing alternative energies is whether they are actually a viable replacement for fossil fuels. Many people are entrenched on either side of the argument, some claiming that renewable energy technology is the future, and others that believe renewable energy technology is too expensive.

One proponent of alternative energies**,** Arjun Makhijan**,** Doctor of nuclear fusion and President of the Institute for Energy and Environmental Research claims that:

"The U.S. renewable energy resource base is vast and practically untapped. Available wind energy resources in 12 Midwestern and Rocky Mountain states equal about 2.5 times the entire electricity production of the United States... Solar energy resources on just one percent of the area of the United States are about three times as large as wind energy, if production is focused in the high insolation areas [strong sunlight] *in the Southwest and West…"* ("Can alternative energy," 2009)

At first glance this quote appears to be extremely enticing, but the facts about this must be examined. Dr. Makhijan does not specify whether these energy amounts are theoretical or applicable values. For example a 100kW wind turbine could theoretically produce 2.4 MW of energy a day, but in a good location a solar panel will likely produce 30-40% of that, or 720-960kW of electricity. Also a good solar cell is only 18% efficient, thus if the values presented are theoretical the land areas needed would need to be tripled and quintupled, respectively. Many of the other proponents of renewable energy argue similar facts along with the idea that eventually fossil fuels will run out and at that point the only energy sources left for us will be alternative fuels. David Moore, *Vice President* of the Institute for Local Self-Reliance, notes that oil only produces "…3 percent of our [the United States] electricity." This is important because it notes that even if the United States were to completely eliminate fossil fuels in electricity production, a large quantity of fossil fuels would still be burned in the transportation industry, unless said transportation methods were replaced as well, by potentially either electric or hydrogen vehicles. The reason this is directly important though is that in the case of hydrogen vehicles, a fuel cell alongside renewably generated electricity would be the ideal system to create hydrogen.

Opponents of renewable energies often cite the idea that wind and solar are not constant in their production of electricity, which is certainly true. Peoples' words once again must be carefully considered as seen in the following quote from Tad W. Patzek, doctor of chemical engineering and Chairman of the Petroleum and Geosystems Engineering Department at the University of Texas at Austin, and David Pimental, PhD, who claim that:

"*We want to be very clear: solar cells, wind turbines, and biomass-for-energy plantations can never replace even a small fraction of the highly reliable, 24-hours-a-day, 365-days-a-year, nuclear, fossil, and hydroelectric power stations. Claims to the contrary are popular, but irresponsible...*
We live in a hydrocarbon-limited world, generate too much CO2, and major hydropower opportunities have been exhausted worldwide..." ("Can alternative energy," 2009)

This quote seems to be extremely harsh and condescending of alternative energies, and perhaps it is, regardless though it does reinforce a valid point that solar cells, wind turbines, etc. are not extremely reliable sources of electricity. As previously stated they are not able to provide a constant source of electricity because of their dependence on the weather. Opponents also cite the fact that energy is needed for vehicles and without some form of storage, such as it hydrogen gas or high capacity batteries, alternative fuels will not be able to replace our dependence on oil.

Regardless of the true rate at which current electricity generating fuels will expire, a transition to alternative energy producers will be an important step for humans. These systems can help reduce CO_2 emissions that currently have many scientists worried. As previously stated if global warming turns out to be just a theory then the immediate need for alternative energies will be quelled, and the question surrounding them becomes how much money should be invested in them so that money is not wasted but progress can still be made in developing the technologies.

A Brief History of alternative energy development

The current need for alternative fuel began in the 1970's when a gasoline shortage started taking hold around the world. Scientists of the world realized life on earth relied very heavily on gasoline. They started looking for other fuels to diminish our dependence. From there, ethanol was used as a combustible fuel source, as well as hydrogen, methane, and propane. At the time, alternative energy was anything that could be used as an alternative to the energy supplies that were already in use (History of alternative energy. (2010)).

Since this time, alternative energy has become synonymous with green technology. Alternative energy is technology developed to produce alternative forms of energy to meet the increasing needs of human life, and that is safe for the environment. Alternative energy is now being developed as a renewable energy source that can replace the fossil fuels we use today. As time progresses, the amount of fossil fuels in the world will greatly diminish, and at the rate fossil fuels are currently being used, some will be completely depleted by the end of this century.

Green Technology has been around for hundreds of years. One alternative energy source is the wind. Wind has been used since 5000 B.C. to power small boats. Later, around 200 B.C. humans started using wind mills to help with a multitude of tasks, such as pumping water and grinding grains. This technology was transported to Europe from the Middle East by merchant traders who traveled between the two regions. In Europe the Dutch applied the wind mill to help drain marshes and lakes located near the Rhine River delta. As different countries entered the industrial revolution, the uses of coal and steam engines led to a decline in the usage of wind power. The new technologies of the revolution also benefited the advancement of wind power by allowing people to build larger wind turbines that could be used to harness wind power and transform it into electrical energy. These turbines for electricity production first appeared in Denmark around the turn of the century in 1890. Since WWII the interest in wind power has been closely related to the price of oil ("History of wind," 2005). The first green technology to be put into use in the United States was the windmill. It dates back to at least the 1600's when the Dutch brought them to America and started using them in what is now New York State. .

Solar energy was discovered in the 1800's by Edmund Becquerel as he studied the ability of plants to turn sunlight into energy. In 1860, Auguste Mouchout patented the first design for a motor running on solar power. He managed to turn solar power into mechanical steam power and power a .5 horsepower steam engine, but his research was cut short when the French government outsourced to England for coal. In 1876, William Adams began experimenting with mirrors in order to control solar power and succeeded in powering a 2.5 horsepower engine. Charles Fritz managed to convert solar power into electricity with a 1 to 2% conversion rate in 1883 ("Solar Energy History", 2006).

Nuclear energy was once considered a green energy form because it does not produce any greenhouse gas emissions; however, the nuclear waste material it produces is harmful to the environment. The waste doesn't just simply go away either, and actually has a very long half-life that leads it to have to be stored for a long time. Due to the nature of these emissions, it was decided not to include nuclear power in this report.

Geothermal energy is the use of heat from the earth as an energy source. The first known use of geothermal energy was over 10,000 years ago by the Paleo-Indians of America. They would use hot springs as a way to heat homes as well as bathe.

In 1864, geothermal energy was first put into use in the United States when a hotel in Oregon used it to heat their rooms. In 1892, the world's first heating system was built in Idaho using geothermal energy to heat buildings. By the end of the 1800's, the Italians used geothermal energy in the Larderello fields to extract acid from the hot pools. In 1904, a generator was attached to a steam powered engine in the Larderello fields that powered four light bulbs and was the first time geothermal was used to make electricity. By 1911, the Larderello Fields had a geothermal power plant capable of producing 250 kW, and by 1975, it was capable of 405 megawatts. Today, the largest group of geothermal power plants is located at The Geysers in California and it produces over 750 megawatts of power. Geothermal energy is only responsible for less than 1% of the world's energy supply, but is expected to supply 10%-20% of the world's energy needs by 2050 (History of Geothermal Energy (2008)).

The reason this paper focuses mainly on wind and solar energy is they are the most directly comparable to the Bloom Energy Server. Both can be installed in sizes similar to the Bloom Energy Server. Also they can both be installed in many different locations, unlike hydroelectric which must be located on moving water.

The Electric Grid

One of the reasons these systems are important is because of problems with the electricity grid, and the advantages that alternative sources can provide.

The first commercial electric grid to be implemented in the United States was started by Thomas Edison on September 4th, 1882. The grid ran through Pearl Street in downtown Manhattan and supplied electricity to some of the businesses there. Electricity from the grid was originally very expensive and only the wealthy, like multi-millionaire JP Morgan, could afford it, but the pricing for it quickly dropped.

By 1932, 70% of Americans were connected to and receiving power from the grid. The price of electricity had dropped to a third of its original price. It was considered a form of alternative energy to the original gas lighting most homes used. It was also preferred over gas because it had the ability to power other things such as appliances and factory machines.

Edison's original design for the grid was to have a power station that would carry electricity through the electric grid to electric appliances by using direct current. The issue with this idea was that at the time it was difficult to transmit direct current without significant transmission losses. That issue was solved by George Westinghouse. Westinghouse incorporated alternating current into the design and was able to transport electricity 26 miles from the dam in Niagara Falls to Buffalo, New York (Niles, Raymond C. 2008).

The grid has basically remained the same since the early 1900s. The grid was first seen as an almost perfect system with very few flaws. Recently though, many flaws have begun to appear. In 2003, a power station in Ohio was disrupted by trees the station failed to trim. The situation escalated due to failing computer systems and poorly trained employees. As a result, 50 million people were left without power from Detroit to New York and 10 billion dollars were spent to repair the damage. It was realized then, the grid needed to be replaced, or at least upgraded (Basic Failures by Ohio Utility Set off Blackout, Report Finds (2003, November 20th)).

Replacing the grid is a huge task. The electric grid is an old outdated system with many issues that are just recently being addressed. In February 2009, an economic stimulus bill was passed that set aside 11 billion dollars for the purpose of upgrading the electric grid. However, it's not nearly enough to fix the entire grid. It will take hundreds of billions of dollars to upgrade the entire grid to what is being referred to as the smart grid.

The smart grid is a grid that self regulates the electricity output based on the demand. A computer cable would be attached to the power lines which would then be able to monitor and manage the grid faster and more efficiently than humans. People would be able to use the internet to change electric settings on appliances and their heating systems in order to manage how much electricity they used.

The issue with something like the smart grid is the price. As of 2008, Boulder, Colorado became the first city to be installed with a smart grid thanks to Xcel Energy. For a city of 100,000 people, it cost over 100 million dollars to outfit the city with the new system (Brady, Jeff (2009, April 27th)). That is roughly $1,000 a person. There are about 308 million people living in the United States. To bring a smart grid to the whole United States could cost around $308 trillion.

If Bloom Energy could actually replace the entire electric grid, it would not come without additional consequences. As of 2007, there were approximately 387,000 employees working for the electrical grid (The Electric Power Transmission and Distribution Industry (2010)). If Bloom were to replace the grid, theoretically there would be 387,000 jobs eliminated, and there would be an unknown number of jobs created. In a struggling economy, eliminating these jobs would be very detrimental to the country, but that's assuming Bloom could actually replace the entire grid.

In order to actually replace the grid completely, it would take 4.5 million of Bloom's energy servers running at max capacity. At the cost of a current Bloom energy server, that would be 3.5 quadrillion dollars to replace the grid. At Bloom's current rate of production (one energy server per day) it would take Bloom approximately 12,000 years to fully replace the grid in the United States. This clearly shows that replacing the grid would be a lengthy process. Although this is obviously unrealistic, it puts into perspective how much money it would cost for Bloom Boxes to make a dent in the United States electricity generated carbon footprint.

A Timeline of Bloom Energy

Even though public awareness of the Bloom Box fuel cell was recently sparked by the companies' appearance on 60 minutes on February 21, 2010, Bloom Energy has been around for over ten years.

Bloom Energy, located in Sunnyvale, California, was founded in 2001 by Dr. KR Sridhar. At the time, Dr. Sridhar was the Director of the Space Technologies Laboratory at the University of Arizona. Dr. Sridhar was leading a group that was supposed to design a device that could take gases found on Mars and creates oxygen, making life on Mars sustainable. When the project was discontinued in 2001, Dr. Sridhar decided that the device could potentially be useful on Earth as a clean energy source. The machine was designed to take fuel and electricity to produce oxygen, but by reversing the process, it could be provided with fuel and oxygen to make electricity. Thus Dr. Sridhar started a company, originally called Ion America but later renamed it Bloom Energy in 2006, a company focused on solid oxide fuel cell development.

After searching for financial backing, John Doerr and Kleiner Perkins became the first investors in Ion America in 2002. Over the years, more people have joined in such as General Colin Powell, T.J. Rodgers (founder, president, and CEO of Cyprus Semiconductor Corporation), Scott Sandell of New Enterprise Associates, and Eddy Zervigon of Morgan Stanley.

In 2002, the company moved to Silicon Valley to set up their business in the NASA Ames Research Facility. There they began designing concepts, developing prototypes, and eventually created an actual product. The first trial run was a 50kW unit that was shipped to the University of Tennessee in 2006. The University of Tennessee monitored the unit for two years; while simultaneously a 25kW unit in Alaska was monitored by the Department of Energy (NASA™ technology comes to earth (n.d.)).

In 2008, Bloom Energy produced their first 100kW commercial sized fuel cell which was purchased by Google in July to help reduce Google's carbon footprint. Since 2008 many companies have become Bloom Box owners such as Adobe, eBay, Wal-Mart, Staples, and Bank of America (Bloom Energy Announces Industry-Leading Customers (2010, February 24th)).

In January 2011, Bloom Energy announced and launched their Bloom Electrons program. Through this program, customers will be able to buy electricity from Bloom without having to purchase a Bloom Box. Bloom will install the server for the customer, own and maintain the server, and the customer will just pay for the electricity being used at a locked in rate for a required ten years. The Coca Cola Company is already a known customer of the program (Bloom Energy: You pay for the juice, not the box 2011, January 20th).

Simply by examining the articles written by different news organizations about Bloom immediately following their press release about Industry leading customers a lot can be learned about the company and what may occur in the companies near future. CNN reported that Bloom lost $85 million dollars in 2008 and that the company still faces the same challenge that all fuel cells companies face, economic viability. This viability will not come until a market for fuel cells that can be cheaply produced is created[1]. Newsweek reported similarly that a Bloom Box costs between $700,000 and $800,000, making it expensive at $7-$8 per a watt (Zakaria, 2010). Many media members have also noted that the price of the Bloom Box was and still is only economically viable when incentives for the fuel cell offered by California are included in the price. An analysis given by CBS news made several interesting comments on other fuel cell programs specifically that GE dismantled its fuel cell program in 2005 and that Siemens has been attempting to sell its program. This is important to note because both companies have large sections in the energy sector. Also at worst a Bloom Box operates at the same efficiency of highly efficient natural gas combustion plants ("The bloom energy," 2010). New Scientist, an international science magazine, noted that the fuel cell was not actually invented by Bloom, and that many other companies had already developed fuel cells that work at lower temperatures than the Bloom Box (Barras, 2010). More recently, in early February 2011, Energy and Capital, an investment analysis website, claimed that the Dow Jones VentureWire had reported that Bloom had received another $100 million dollars in funding from Kleiner Perkins, NEA, and Morgan Stanley. More recently some articles have begun to raise questions regarding the continued government subsidies being provided by California, and whether that assistance is justified. In a recent article Dan Morain of the Sacramento Bee points out that due to the amount of money spent subsidizing Bloom Energy the public utilities commission recently suspended the program providing the funds. Between 2009 and 2011 the program granted $210 million to Bloom Energy in payments and commitments (Morain, 2011). Going forward the question of continuing state subsidies for the Bloom Box will likely play a significant role in the company's development.

Solid Oxide Fuel Cells

As previously stated, the Bloom Energy Corporation produces solid oxide fuel cells. To properly understand the discussions of the patents presented later in the paper, a brief description of the technology, based on a fuel cell design handbook, is provided.

A solid oxide fuel cell (SOFC) is composed of four distinct parts: an electrolyte, an anode, a cathode, and an interconnect. Each part serves a distinct purpose in the fuel cell. Ultimately the purpose of an SOFC is to take a fuel input and produce electrical output. In general this occurs through the oxidation of hydrogen and carbon monoxide. This reaction creates a potential difference across the

SOFC which is an electrical voltage. This potential difference can be calculated by the following equations where R is the gas constant and F is the Faraday constant.

$$U_0 = -\frac{\Delta G_{f,H_2O,T}}{2F} + \frac{RT}{2F} * \ln(\frac{\sqrt{p(O_2)_{cathode}}p(H_2)_{anode}}{p(H_2O)_{anode}} \quad (1)$$

For the oxidation of hydrogen and:

$$U_0 = -\frac{\Delta G_{f,CO_2,T}}{2F} + \frac{RT}{2F} * \ln(\frac{\sqrt{p(O_2)_{cathode}}p(CO)_{anode}}{p(,CO_2,)_{anode}} \quad (2)$$

For the oxidation of carbon monoxide.

It should be noted that in each of these cases $\Delta G_{f,H_2O,T}$ is a linear function and thus the potential decreases with temperature increases. The reason this is important is because of the differences in operating temperatures between the Bloom, Ceres, and Topsoe fuel cells which will be discussed in the technical information section (VIELSTICH, GASTEIGER, & LAMM, 2004, p. 335-336). The purpose of the electrolyte in an SOFC is to separate the oxidizing and reducing gas atmospheres and allow a method for which the oxygen ions produced at the cathode can diffuse to the anode. The electrolyte must have reasonable conductivity of oxygen ions as well as chemical stability in both reducing and oxidizing conditions. Typically the electrolyte is made out of yttria stabilized zirconia (YSZ) although other possible materials include doped ceria and perovskites, both of which are discussed in Bloom Energy's patents.

The purpose of the anode of the fuel cell is to oxidize fuel in the presence of oxygen ions from the electrolyte (which were produced at the cathode of the SOFC). The oxidation occurs as dictated by the following equation:

$$Red_g + nO_O^x = OxO_n + nV_{\ddot{O}} + 2ne^-$$

Where Red_g is the reduced fuel species, Ox is the oxidized fuel species, O^x_O is an oxygen ion on the electrolyte, and V^{-}_O is a vacant spot in the electrolyte. What this equation states is that a reduced gas and n oxygen ions produce the oxidized fuel species, which contains n oxygen atoms, n vacant sites for oxygen ions and 2n electrons. A typical SOFC anode is made from a nickel YSZ combination. Two of the major issues with using this compound are coke formation and the re-oxidation of nickel. As will be discussed in the technical information section, it appears that Bloom Energy has found managed to work around the re-oxidation of the nickel (VIELSTICH, GASTEIGER, & LAMM, 2004, p. 338-339).

The purpose of the cathode of the SOFC is to reduce gaseous oxygen to oxygen ions which are then absorbed by the electrolyte. This reaction is governed by the following equation:

$$O_{2,g} + 4e^{-} + 2V_{\ddot{O}} = 2O_{O}^{x}$$

This equation states that oxygen in a gaseous state, 4 electrons, and two Vacant places in the electrolyte yields two oxygen ions. Due to the highly oxidizing nature of the cathode environment, metal substances cannot be used as the cathode. The cathode must be chemically compatible with the electrolyte. Cathodes are often multi-layered, with the layer closer to the electrolyte being more chemically compatible while the layer closer to the oxidizing atmosphere is optimized for electronic conductivity and porosity so that it can create more oxygen ions. Typically the cathode of an SOFC is made of a compound based on perovskite lanthanum manganite, such as $LaCoO_3$, $LaFeO_3$, $LaMnO_3$, or $(La,Sr)MnO_3$. Typically $(La,Sr)MnO_3$ is considered to be the best cathode material to be used with a YSZ electrolyte at high temperatures. The cost of the materials in the cathode is greatly dependent on the purity of the lanthanum, and thus any reduction in the purity can greatly reduce the cost of the SOFC (VIELSTICH, GASTEIGER, & LAMM, 2004, p. 339-340).

The interconnection is another important part of an SOFC. The interconnect works mainly to conduct electricity between the different cells of the whole fuel cell system. The interconnection must be gas tight to prevent leakages from occurring. It must also be able to handle being exposed to highly oxidizing and reducing atmospheres just like the electrolyte. As the heat in the SOFC increases the interconnection must be made of more expensive materials and thus reducing temperature of the SOFC allows for a cheaper interconnect to be used(VIELSTICH, GASTEIGER, & LAMM, 2004, p. 341).

Technical Information

The following sections include all technical information relating to the discussed technologies.

Solid Oxide Fuel Cells

The following sections pertain to three different solid oxide fuel cells: The Bloom Box, the Ceres Power fuel cell, and the Topsoe fuel cell.

The Bloom Box

Starting with its press debut on 60 Minutes in February 2010, Bloom Energy has been publicly promoting their Bloom Energy Server. The Bloom Energy Sever is a solid oxide fuel cell (SOFC) which converts the chemical energy of hydrogen into electrical energy. Bloom's energy servers are built by combining enough single ceramic plates with special inks on each side that serve as the anode and cathode. Each of these plates has been improved to produce about twenty five watts of power ("Alternative energy: the," 2010). The plates are stacked together until the total power produced is one hundred kilowatts. This means about 4000 plates have to be stacked together. The output from the fuel cell is naturally in the form of direct current (DC), but as most technology is built to run on alternating current (AC) the energy server comes with the necessary conversion to 480 volts three phase AC ("Es-5000 energy server," 2010). 480V is typically delivered on local transmission lines; a 4-to-1 transformer can be used to step down this voltage to 120V with minimal losses if needed. Bloom energy has made several claims regarding their fuel cell design progress that fixes some of the previous issues with fuel cell technology.

The first major issue that fuel cells have had in the past is the fact that they need precious or noble metals, predominantly platinum, which at around $1800/oz ("Price charts,") drive the cost of manufacturing higher than would be profitable. SOFCs avoid the need for platinum by operating at a high enough temperature (500-1000^{o}C) so that the chemical reaction can occur without platinum as a catalyst (VIELSTICH, GASTEIGER, & LAMM, 2004, p991). Unfortunately by increasing the operating temperature, the other materials in the fuel cell have to change as well, and coefficients of thermal expansion for the cathode, anode, electrolyte, and interconnect must be matched so that the fuel cell doesn't tear itself apart. Thus although the goal is to reduce the cost of the fuel cell by eliminating platinum, the cost of the other components tends to increase. Additionally operating at higher temperatures tends to result in significant heat losses, and increase the energy used when the fuel cell starts up. Currently a fuel cell from Bloom Energy has been estimated to cost the consumer anywhere from $700,000 to $1 million for a 100kW system, although $700,000 to $800,000 is a far more common estimate. That equates to between $700 and $1,000/kW before subsidies are taken into account. Unfortunately with government and state level subsidies it can be difficult to tell what price is being quoted; whether it is before or after subsidies are taken into account (Correspondence with Bloom Energy).

Additionally from the data sheet for the ES-5000 energy server, the bloom box consumes .661MMBTUs of natural gas per hour and produces 100kW of AC power. The fuel must be supplied at 15psig, and 120 gallons of water are required at startup. The reason that a constant water supply is not required is because a Bloom Box has anode gas recycling. This recycles the steam and allows the fuel cell to operate without needing a water supply, and is included in patent 7,591,880. The data sheet currently lists the efficiency at >50%, but reports from Dr. Henry McDonald from the University of Tennessee state their unit, installed in 2006, operates at an efficiency level of 49%. However, he has been told that "a 200Kw unit is entering limited service and is achieving 60% efficiency" although there has been no official notice from Bloom Energy (Correspondence with the University of Tennessee). The discrepancy in efficiency is likely due to improvements in the technology since the energy server was installed in 2006. Since the data sheet was published in 2010, it is likely the specifications of the current level of the Bloom Energy Server ("Es-5000 energy server," 2010).

From the data given by the data sheet and the testament of Dr. Henry McDonald we can draw some conclusions about the Bloom Box's performance and extrapolate that into some useful data. First by taking the average costs of electricity and natural gas in different states, we can calculate the time line for average return on investment in each of those states for residential, commercial, and industrial customers, as shown in charts A, B, C, F, and G.

Some apparent benefits of the Bloom Energy server are the low emissions produced by the Bloom Box. Nitrous oxide, sulfur oxide, carbon monoxide, and Volatile organic compounds (VOCs) emissions are all below .1lbs/MW-hr, with sulfur oxide emissions being listed as negligible. Carbon dioxide is the only sizeable emission at 773lbs/MW-hr when run on natural gas, or carbon neutral when run on directed biogas. Compared to the average natural gas fired power plant which produces about 1135 lbs/MWh of carbon dioxide, the Bloom Box reduces carbon emissions by about 30% ("Clean energy," 2007). On directed biogas, or biogas, the Bloom Box is carbon neutral because in theory any CO_2 released from the biogas was removed from the environment by the biological material while it was alive and is simply being rereleased into the atmosphere.

Finally, from the data sheet and correspondence with Bloom, the requirements for installation for a single ES-5000 energy server are provided. Each 100kW box is about 19ft long, 7ft tall, 7ft wide, and weighs 10 tons. The servers are installed outdoors on a concrete pad which is installed by Bloom Energy as well. Also the Bloom Box is intended to operate between 0 and 40^{o}C, and below 6,000ft. Another advantage of the Bloom Box is it produces little noise (<70dB) particularly when compared to traditional combustion generators ("Es-5000 energy server," 2010). These specifications are important when considering where a Bloom Box can or cannot be installed. The low noise output from the Bloom Box is lower than a typical generator allowing the Bloom Box to be placed closer to popular areas without as much trouble. The dimensions of the Bloom Box are important as well for determining suitable locations.

One way to measure Bloom's success in improving the idea of a SOFC is to analyze the patents that have been approved, or are in the process of being approved. To view Bloom's progress over time the notable patents will be examined in chronological order beginning with patent 7,255,956 which was filed on February 20, 2003. This patent is for an Environmentally Tolerant Anode Catalyst for a Solid Oxide Fuel Cell. The claims for this patent are that by making the anode of a SOFC comprised of a cermet consisting of nickel, a stabilized zirconia, and a catalyst that does not include rubidium, the anode will be able to resist breaking when not enough fuel is available to the anode. Additionally the patent reveals the catalyst to be, at that point, platinum, palladium or rhodium which are all noble metals. Finally it establishes the SOFC design as being electrolyte supported with samaria doped ceria sandwiched between two yttria stabilized zirconia layers. An electrolyte supported fuel cell means that the electrolyte is used to maintain the structural integrity of the fuel cell, and as a result the electrolyte is thicker and requires a higher temperature to operate (Barras, 2010).

The next patent chronologically is patent 7,482,078, Production of Hydrogen and Electricity in a High Temperature Electrochemical System, filed on May 29, 2003. This patent proposes using some of the electricity generated to power the steam reforming process while in operation. Additionally it points out the possibility of taking some of the reformed hydrogen and using it for other purposes such as hydrogen powered car fueling while the fuel cell still produces (less) electricity. It also reveals that the more current that is drawn, the more fuel required. It also points out that CO can be used as a fuel when combined with water, but this seems a formality and not an efficient method of electricity production.

The next notable Bloom Energy patent (7,201,979) was filed on June 20, 2003, and is for a Solid Oxide Regenerative Fuel Cell (SORFC) System and Method with an Exothermic Net Electrolysis Reaction. The patent is for the idea that a SORFC can be used to store heat, by converting hydrogen to a hydrocarbon as part of a “charge mode,” and a hydrocarbon to hydrogen as part of the “discharge mode.” Essentially the claim is that when electricity and hydrogen are pumped in then the fuel cell can produce methanol, and the stored methanol can be run through the fuel cell to produce electricity and hydrogen. It also uses an exothermic reaction to convert the exhaust gases back into hydrocarbons, and the heat from that reaction is then used to raise the SOFC to its operating temperature.

Patent 7,364,810 was filed on September 3, 2003 for a Combined Energy Storage and Fuel Generation with Reversible Fuel Cells. This patent is a version of the SOFC that produces electricity in fuel cell mode, and fuel and oxidant in reverse mode. The two modes can be cycled as needs change such as fuel cell mode 16 hours and then reverse 8 hours. Additionally, the patent claims more fuel is generated in electrolysis mode than is needed to operate the system in fuel cell mode therefore allowing longer running time in fuel cell mode than in electrolysis mode. For this to work in the above example with the fuel cell running in reverse half of the time, the current would need to be doubled.

Patent 7,150,927 was filed on September 10, 2003 for a SOFRC System with Non-Noble Metal Electrode Composition. It is an Improvement on patent 7,225,956 with options of 20% noble metals, less than .1% noble metals, or no noble metals. It gives options for the compounds used in both positive and negative electrodes. The positive electrode or cathode is listed as possibly being composed of LSM, LSCo, LCo, LSF, LSCoF, PSM, or a combination of the aforementioned compounds. The preferred compound seems to be LSM or lanthanum strontium magnate which is considered the best cathode to use with an YSZ electrolyte. The negative electrode is listed as containing Ni, Cu, Fe or a combination of them with an ionic conducting phase. The preferred anode seems to be a Ni – YSZ cermet with less than $1mg/cm^2$ concentration of a noble metal. Additionally, the patent discusses how the anode and cathode are connected to the electrolyte, and the thickness of each part. The anode is listed as being 27 micrometers (um) thick, the cathode is 39 um thick, and the electrolyte is 300 um thick. The anode and cathode are both screen printed on to the electrolyte, and then fired at over 1000^oC.

Patent 7,575,822 was filed on June 14, 2004 for a Method of Optimizing Operating Efficiency of Fuel Cells. This patent discusses potential applications for the fuel cell and ways to optimize it for power, hydrogen and power, and forward->reverse cycles for several different potential applications. One point of the patent is the option for the operator controlling the hydrogen from the steam reformer to be either store for late use, used in the fuel cell to produce electricity, or used in some other application such as fuel for a hydrogen powered car. This would decrease the amount of electricity produced but make the fuel cell more versatile. The example given in the patent takes a 100kW unit and uses 50-80% of the fuel to produce 70-110kW of electricity, and 45-110kg of hydrogen per day. The patent claims that this will reduce the cost of producing hydrogen. It also explains that this same method of separating hydrogen can be used when the fuel cell is running in reverse if more electricity and reactant product are supplied than are needed to produce the necessary fuel.

Patent 7,422,810 was filed on December 3, 2004 for a High Temperature Fuel Cell System and Method of Operating Same. The patent discusses thermal integration of the stack and reformer to use the excess heat to reduce the need for combustion to sustain the reformer, as well as different ways to possibly reform the hydrocarbon into hydrogen. First the desulfurizer and water-gas shift reactor (a reactor that combines H_2O and CO to form H_2 and CO_2) are thermally integrated so that the waste heat from the reactor heats the desulfurizer. A start-up burner is also integrated thermally with the reformer. This allows the fuel cell to start up without needing to flood the SOFC with an inert gas at startup. The thermal integration of the different components allows an increase in the efficiency of the fuel cell by reducing the amount of fuel being used to heat the system. The reformation of the fuel into hydrogen takes place outside of the stack because otherwise the heat consumed by the reformer can put thermal stresses on the fuel cell stack. Finally the patent claims that once the fuel cell reaches its typical operating temperature the start-up burner can be turned off, and the heat produced by the fuel cell reactions is enough to maintain the reformer at its necessary operating temperature. The patent concludes the best set up is to have the reformer between the combustor, and one or more stacks to assist the heat transfer.

Patent 7,514,166 was filed on April 1, 2005 for a Reduction of SOFC Anodes to Extend Stack Lifetime. This patent is a possible genuine breakthrough that allows the anode to be basically returned to new in about 45 minutes, which can result in an extended lifetime and reliability for the fuel cell. Previous methods for doing this could take days, and hydrogen, and many places wouldn't be able to lose power for several days as well as import hydrogen. As the fuel cell operates the nickel in the anode naturally begins to oxidize into nickel oxide. Bloom Energy's patent lists two possible methods for restoring the nickel oxide to nickel. The first is to idle the fuel cell while the anode side is flooded with a hydrogen containing gas, preferably pure hydrogen, and the second is to electrochemically reduce the nickel oxide to nickel. The electrochemical process is the new method that is easier and quicker than the chemical method. For the electrochemical method, a DC source is connected to the fuel cell with the positive lead going to the cathode and the negative to the anode. The inventors believe that the oxygen is pumped through the electrolyte to the cathode side and thus separated from the nickel. The listed operation conditions are a constant voltage of .9 volts, and a current that starts at 0 or slightly negative and rises to a peak of 200mA. These values result in the fuel cell being restored in about forty-five minutes. While the process is going on the fuel cell needs to be between 800 and 900^{o}C. The frequency at which this process might be necessary is not included in the patent.

Patent 7,524,572 was filed on April 7, 2005 for a Fuel Cell System with Thermally Integrated Combustor and Corrugated Foil Reformer. This patent gives the design for a thermally integrated combustor, reformer, and stack. It also explains how the heat transfer should mostly balance out so that the combustor is only used at startup and to regulate heat flow.

Patent 7,591,880 was filed on July 25, 2005 for a Fuel cell anode exhaust recovery by absorption. This patent describes Bloom Energy's method of recovering different components out of from the exhaust from the anode side of the fuel cell. By recycling the water from the exhaust they can eliminate the need for a constant water supply. Their process condenses and removes at least a part of the water and then re-circulates it into the steam reformer. Additionally the patent discusses methods for capturing fuel and hydrogen from the exhaust stream, and reusing them in their respective parts of the fuel cell.

Patent 7,572,530 was filed on May 12, 2006 for a SOFRC Power and Oxygen Generation Method and System. This is a design for using the fuel cell in an enclosed environment as a backup power source, and primarily as a way to generate fuel and oxygen. This patent serves to show some niches where the Bloom Box would be likely to see success, although there have been no announcements of the Bloom Box being used for anything other than electricity generation. The examples given in the patent are areas where fuel storage, oxygen generation, and backup power generation are needed, such as underground, underwater operations, or possible outer space applications. For the average company or person looking to buy a fuel cell for power generation these applications are useless but it shows a potential market that Bloom Energy seems to have avoided, possibly because it requires special modifications to their Bloom Box and at the current rate of production (one per day) they do not have the ability to quickly switch production to a different configuration.

Patent 7,833,668 was filed on March 30, 2007 for a Fuel Cell System with Greater Than 95% Fuel Utilization. This is a design for the reformer so that 95%, 99%, or 100% of the hydrogen in the fuel is used in the fuel cell, through exhaust recycling. The patent indicates that not all of the hydrogen supplied to the cathode of the fuel cell will be utilized during the reaction and some of it will be sent out with the exhaust stream. By taking the exhaust stream and filtering out the hydrogen, chemical energy will not be wasted. Also, the more hydrogen used, the higher the efficiency of the conversion from chemical to electrical energy. The process described in the patent is that the exhaust stream is sent to an electrochemical separation unit such as a proton exchange membrane, with at least two membranes arranged in fluid flow series. The overall system is set up so that the exhaust from one set of cells is fed into the next set. Proton exchange membranes or PEM's are used in another type of fuel cell as the method for generating electricity. For the PEM to remain effective, the exhaust needs to be humidified, and where the exhaust is reconnected to the fuel supply, the temperature must be between 80 and 90^{o}C. According to the patent, 25% of the hydrogen makes it to the exhaust stream where the system separates between 95% and 100% of the hydrogen from the exhaust stream .This hydrogen is recycled back into the fuel cell system. The patent claims that without recycling the fuel cell would only have an efficiency of 45%. If the system recycles 85% of the exhaust and uses 75% of the hydrogen per pass, then the fuel cell would have an AC electrical efficiency of 50% to 60%. However, all evidence available shows that Bloom has been unable to pass about 50% efficiency in the Bloom Box at the time of this report.

Patent 7,704,617 was filed on April 2, 2007 for a Hybrid Reformer for Fuel Flexibility. This is a design for a reformer that has higher concentrations of nickel at one end that gradually reduces along the reformer so that any hydrocarbon can be put in and reformed in the same reformer thereby reducing power consumption and allowing for increased efficiency. The design of the reformer seems to be a cylinder, coated with a catalyst on the inside for the fuel to pass through. The catalyst is composed of nickel and rhodium, and the concentration of nickel along the cylinder varies to reform different types of fuel. At the inlet the concentration of nickel is lower to reform high hydrocarbon fuels such as diesel, and the concentration increases monotonically along the reformer to reform fuels with lower hydrocarbon fuels such as methane. The concentrations of nickel can be optimized depending on the typical fuel, but the overall design allows the reformer to accept a range of fuels without needing to modify the reformer. An alternate design option listed is to keep the concentration of nickel constant throughout the reformer and instead adjust the concentration of rhodium, opposite of the way the nickel was graded (inlet has a higher concentration of rhodium than the outlet.

Patent 7,705,490 was filed on May 7, 2007 for an Integral Stack Columns. This patent discusses different ways of electrically converting the output to what is needed as fuel cells have a limited current carrying capability. As such these converters are needed to supply a standard electrical connection. The patent describes how Bloom Energy decided to convert the DC power produced by a fuel cell into an AC output that most technology currently runs on. Additionally the DC to DC converters are used to control the current from individual stacks to optimize fuel usage. For the most part the patent simply explains the connections of numerous DC to DC converters and DC to AC converters to integrate the different stacks into a single output while maintaining control over the electrical draw from each individual stack. In addition to the patents already discussed, Bloom Energy holds several patents for computer controlled systems that could be used to operate a SOFC to increase the efficiency of the fuel cell's operation. This along with the improvements that each of the aforementioned patents contain, represent the best publicly available summary of Bloom Energy's technical accomplishments to date. Most of the improvements focus on optimizing the traditional SOFC design, with the goals of reducing cost, improving performance, and increasing lifespan.

Ceres Power

Ceres Power is a fuel cell company based in the United Kingdom that has been developing home sized fuel cells for the past ten years. The company is based on technology developed at Imperial College during the 1990's ("Company overview,"). The company has been designing a combined heat and power system that uses a new material for the electrolyte. They claim that this allows it to operate between 500 and 600^{o}C. A SOFC running at those temperatures could use stainless steel supports, making them cheaper and easier to manufacture (Barras, 2010).

Ceres Power recently publicly tested their fuel cell on September 29, 2010. Their SOFC is a combined heat and power unit meaning it produces electricity, and uses the heat of the fuel cell (500-600^{o}C) to heat a home's hot water system. The computer controlling the fuel cell can load follow, meaning that as the homes electricity usage changes, the electricity produced by the fuel cell changes to meet those needs within a few seconds. While the fuel cell increases or decreases its power output, the grid either supplies the difference to the home, or receives excess electricity from the fuel cell. The product has met CE safety approval (all products must pass this to be sold in Europe), and has entered field trials in the UK ("Ceres power,"). The unit is capable of producing up to about 900W of net electrical power, as well as dynamically responding to a home's energy need and scaling its power production accordingly. Thermally the unit is rated to be able to produce 25kW (thermal) but to do so can require an auxiliary burner to be activated. Ceres Power plans to have their final product produce between 1 and 25kW electrically. The company's goal is for their unit to replace a home's hot water heater, central heating system, and electrical supplier. The unit primarily runs on natural gas using an internal steam reformer, and has been successfully tested running on LPG and biofuels ("Chp product demonstration," 2010).

Since 2001 the company has raised somewhere between 10 and 100 million pounds through investments, as well as by having gone public in 2004. In 2009 Ceres Power built a production facility with "the capacity to manufacture fuel cells and assemble Fuel Cell Modules to meet the requirements of the Beta and Gamma phases through to initial sales" (Ceres Power Holdings plc, 2010). The company's beta phase has already started with installment of a unit in an employee's home. The rest of the "beta" trial will be completed by March 2011; the "Gamma" trial will start in September 2011; and the final wave of at least 150 units will start in 2012. The purpose of the trials is to test the company's ability to mass produce the CHP Fuel Cell (Ceres Power Holdings plc, 2010).

Ceres power claims that the reason they are able to operate their fuel cell at such a low temperature compared to other SOFCs is because they have replaced the traditional electrolyte made with yttria stabilized zirconia, they are instead using a family of ceramics known as cerium gadolinium oxides which allows the SOFC to work at 500-600^{o}C ("The Ceres cell,"). This then allows the cell substrate to be made of stainless steel. Since the electro chemical layers do not need to structurally support the fuel cell they can be made very thin, increasing power density, and decreasing cost. Additionally the metal supports are more mechanically sound than ceramic ones making the unit more durable.

Patent GB2394114 (A) was filed on April 14, 2004 for fuel cells and anode compositions for intermediate temperature solid oxide fuel cells (IT-SOFC) stacks designed to operate at or below 700 ^{o}C, processes for preparing fuel cells and their uses. The anode compositions are substantially free from nickel and comprise a conducting oxide incorporating a d<10> cation (positively charged atom) which may be Zn<2+>, In<3+>, Ga<3+> or Sn<4+>. This invention relates to the materials deemed necessary to operate between 400 and 700^{o}C. The patent lists numerous chemical compounds that could be used in the anode of a fuel cell to improve the performance of an intermediate temperature SOFC (IT-SOFC). The patent also provides specifications for the necessary conductivity of the oxide, types of cations, and cation oxide doping components.

Patent ZA200508144 (A) was filed on October 25, 2006 for the fabrication of ceria based electrolytes to densities greater than 97% of the theoretical achievable density by sintering at temperatures below 1200 ^{o}C, preferably approximately 1000 ^{o}C, is disclosed. The electrolyte has a concentration of divalent cations minus an adjusted concentration of trivalent cations of between 0.01 mole % and 0.1 mole %. This invention relates to "the densification of ceria based electrolytes as may be used in fuel cells and oxygen generators." Previous patents dealt with ways of increasing the density

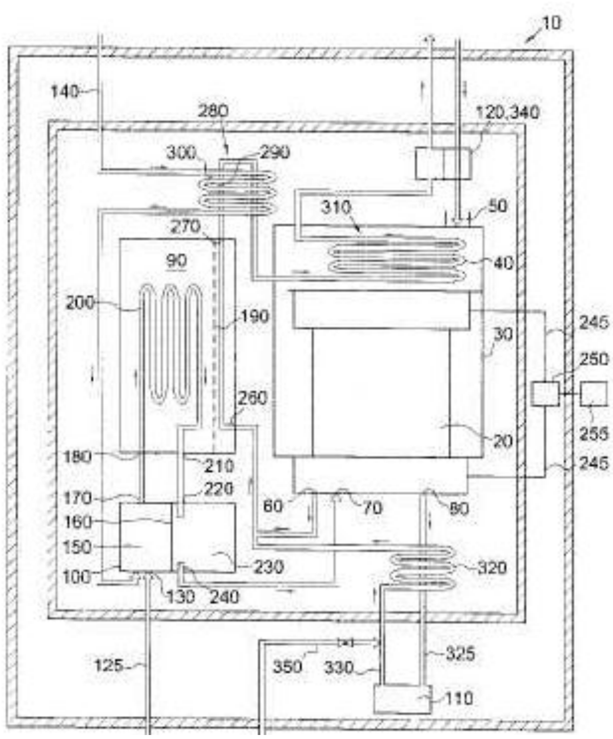


Figure 2 Ceres Power Stack Assembly Design (Patent GB2436396 (A), 2007)

of the electrolyte to 97% of its theoretical maximum value. The patent claims that tests have shown that if small amounts (1- 2mol%) of CuO, NiO or CoO are added to commercial ceria based electrolyte, then pellets pressed from these doped elements can be sintered to densities greater than 97% of the theoretical maximum, and this can be done at temperatures as low as 1000^oC. The denser the electrolyte the less fuel and oxygen can leak out of their respective sides. The disadvantage to this increased density is lower electrical output. A 2mol% addition reduces the electrical output of each plate from about 910mV to 800mV. The inventors claim the optimal addition to be between .3% and .8%mol.

Patent GB2436396 (A) was filed on September 26, 2007 for the design of an improved fuel cell stack system assemblies comprising: at least one fuel cell organized into at least one fuel cell stack defining an open oxidant inlet manifold; and at least one housing enclosure. This patent contains the details of how the entire fuel cell stack assembly combines with a reformer, at least one heat exchanger, system control and electronics, and insulation. The patent also discusses the challenges associated with systems under 50kW in size having significant thermal losses which can impact overall efficiency. The patent proposes using a “hot box” to package all the necessary components as well as making all of the parts as small as possible to mitigate this problem. The patent discusses different ways of connecting the different parts and the effects that each has on overall function and efficiency. The interesting part of the patent is the challenges associated with changing the size, in kilowatts of a SOFC. In Bloom Energy’s press releases and other public announcements they have implied that any number of their fuel cells could easily be stacked together for a custom sized unit. This seems to indicate either Bloom Energy has found a way to compensate for the thermal losses, or the reason they have not produced any units smaller than 100kW is because they have been unable to produce a smaller sized fuel cell that can function efficiently with these thermal losses.

Topsoe Fuel Cell

Topsoe's fuel cell work began in the 1980's under Dr. Haldor Topsoe, and in 2000 shifted to focus on SOFCs. The company went public in 1972 with the shares split 50-50 between Dr. Topsoe and Snamprogetti ENI group. As of 2007 Dr. Topsoe now owns 100% of the shares ("Topsoe milestones,"). In 2004 Topsoe Fuel Cells was established as a separated company owned by Haldor Topsoe. In 2005 a 5kW fuel cell unit was tested with support from Wärtsilä, a producer of maritime power systems and engines. In 2007 a 20 kW unit was tested with Wärtsilä and a 1 kW micro CHP unit was tested with Dantherm Power. In 2008 the company completed a production facility capable of producing 5MW worth of fuel cells in a year ("Milestones,").

The first Topsoe micro CHP units are capable of producing 1kW of electricity and 1kW of heat. The unit can take natural gas, biogas, or biomass as a fuel source, and the first units started field tests in spring 2010, and again in October 2010 with electricians, plumbers, and similar professionals who could easily fix simple issues that may arise. Each unit is about the size of a large fridge to make servicing the units easier. Topsoe plans to have seven units in place by 2011, with 15 more being produced in September 2011 having improvements based on previous testing ("Projects,"). The company has a 20kW unit built to run on methanol currently powering the ship Undine (Lyngby, 2010). Additionally they plan to start selling home sized units in 2015 for between $10,000 and $15,000 ("Topsoe fuel cell,").

Topsoe's fuel cells are anode supported, meaning that the units are structurally connected through the anode of the fuel cell. This allows for a thinner ceramic electrolyte which in turn means that the fuel cell can be operated at a lower temperature than a typical SOFC. Topsoe's fuel cells run at bout 750^{o}C, and this should result in cheaper materials and less energy required at the startup to get the unit running (Barras, 2010).

Patent AU2010241468 (A1) was filed on December 2, 2010 for a method of producing a multilayer barrier structure in a solid oxide cell stack. The goal is to reduce the effects of "chromium poisoning" which damages the catalyst over time. This patent claims its method of coating the electrolyte with chromium resistant layers that can slow the effects of the poisoning.

Patent DK1768207 (T3) was filed on December 13, 2010 for a method of supplying an SOFC with ethanol to produce electricity. The ethanol is converted into methane and then passing the methane over the anode of the fuel cell while oxygen passes over the cathode to generate electricity. The patent appears to show that the company is moving towards making their fuel cell more fuel flexible, similar to what Bloom Energy has done.

Patent WO2010149339 (A1) was filed on December 29, 2010 for a reforming process to prepare the hydrocarbon to be accepted by the fuel cell. This patent details a process for the preparation of hydrocarbons from solid and liquid fuels. The process occurs in two steps; first the gas is converted into an oxygenate, and then the oxygenate is converted to a gasoline hydrocarbon product. The two steps can be integrated or separate producing an intermediate such as methanol. The goal of the reformation process is to produce a liquid comprised of hydrocarbons and a gas comprised of inert gases and methane. The gas is then combined with air and combusts to produce heat and power through a generator. The liquid is then processed into gasoline.

Notable Technical Specifications

From correspondence with Garrett Ruiz of Bloom Energy and correspondence with Dr. Henry McDonald of the University of Tennessee, the Bloom Box appears to function as the data sheet, included as chart E, shows. The unit is 50% efficient at converting the chemical energy stored in natural gas to electrical energy. The Bloom Box has lower emissions than a traditional natural gas power plant, and can run on nearly any hydrocarbon fuel although at unknown efficiencies.

From an analysis of the patents that have been issued to Bloom Energy, there are some conclusions that can be drawn about the Bloom Box. First there are several differences between the Bloom Box and a typical SOFC. The first significant difference comes in patent 7,150,927. The typical dimensions of the anode, cathode, and electrolyte are given in the Handbook of Fuel Cells as 50um, 150um, and 50um (VIELSTICH, GASTEIGER, & LAMM, 2004, p 334). The difference in the thickness for the anode and the cathode could be because Bloom Energy uses a laser to print the anode and cathode to the electrolyte, and as a result they are able to achieve a large enough surface area for the reaction to take place without needing a thicker anode and cathode. The difference in the thickness of the cathode could be because of this. The difference in the thickness of the electrolyte could be because a Bloom Box is electrolyte supported and therefore might need a thicker electrolyte for structural stability. A thicker electrolyte requires higher temperatures for the chemical reactions to occur which could be why a Bloom Box operates at the high end of SOFC temperature ranges (900-1000/600-1000^{o}C). The components listed for the anode, cathode, and electrolyte, are typical of SOFC, although exact ratios are not given and can significantly affect performance. Significant improvements over traditional SOFC designs that appear in the patents are a way to extend stack life in patent 7,514,166, and a flexible fuel reformer design in patent 7,704,617. The method for extending the stack lifetime should undo the oxidation of the nickel, which if left uncorrected will reduce the amount of electricity the fuel cell can produce. By returning the nickel oxide to nickel the Bloom Box can continue to produce 100kW throughout its lifetime, making it better over the long term than a SOFC that does not take steps to correct the oxidation. The flexible fuel reformer allows the Bloom Box to use nearly any hydrocarbon and reform it into hydrogen for the fuel cell to use. Typically the reformer is designed to take a specific hydrocarbon, and a separate part would be needed to change fuels. Unfortunately the only fuels that a Bloom Box has run on are natural gas, and biogas, so there are not many benefits to this improvement. In conclusion Bloom Energy seems to have made a few improvements to the overall SOFC design, but has not made significant changes to the fuel cell itself other than non-standard anode, cathode, and electrolyte thicknesses, based on publicly available information.

In comparison to the achievements of Bloom Energy, both Ceres Power and Topsoe Fuel Cells appear to have made distinctly different improvements to SOFCs. Topsoe has used an anode supported design which allows them to operate their fuel cell at lower temperatures than Bloom Energy, which in addition to decreasing start up energy, directly relates to the amount of voltage a SOFC can generate. As previously mentioned, the higher the temperature of the SOFC, the lower the electric potential across each cell will be. Ceres Power has used a different ceramic for their electrolyte allowing their fuel cell to operate at even lower temperatures, and be able to use steel supports in their fuel cell. Additionally Ceres Power has designed their fuel cell to load follow, so the fuel cell only produces as much electricity as the home currently needs. As of now neither company is at the same point as Bloom Energy currently is, with both Topsoe Fuel Cells and Ceres Power just beginning to perform field trials of their respective products, while Bloom Energy can reportedly produce one 100 kW unit per day. Moving forward, both companies seem to have modified the basic SOFC design more than Bloom Energy and with more promising implications, although Ceres fuel cell is only for residential applications, and Topsoe's for residential customers as well boats.

Solar Energy

One type of green technology that has developed in recent years is photovoltaic (PV) cells. Photovoltaic cells take energy from the sun and convert it into electrical energy. On a clear, sunny day about 1kW of solar energy is deposited on each square meter of the ocean surface. In one hour, enough solar energy strikes the earth to provide mankind with all the energy it uses in a single year. With good weather, an area of about 10,000 Mi^2, about 9% the area of Nevada could supply the US with all of its electrical needs (Nersesian, 2007, p 318).

There are several different types of PV cells currently on the market. Single Crystalline silicon is the most widely available and has an energy conversion efficiency of 14-18%. The expense of the raw materials used to create these PV cells is high, about $20-25 per pound of raw materials. Polycrystalline and semi crystalline methods are cheaper, but the resulting cells are less efficient. Other solar cells with efficiencies as high as 37% percent have been created but these technologies (concentrated solar and multi-junction) are extremely expensive (Patel, 2006, p 153).

Typical PV cells work by absorbing energy that is then transferred to a charge carrier. This creates a potential gradient i.e. a voltage, which results in the charge circulating through any external circuit connected. Most cells are laced with a thin silver mesh that collects current and allows light through. Cells also typically contain an antireflective coating that helps the cell absorb more light by reducing reflections. Finally, a cell is covered in glass for physical protection.

One negative aspect to the way solar panels work is that they are affected by the weather similarly to wind turbines. The less sunlight that is reaching the solar panel, due to factors such as the ozone, cloud cover, etc. the less power that the solar panel will output at a given time. This problem has been alleviated by the creation of systems that will help tilt solar panels into the sun so that the most energy is absorbed. Depending on how much a person is willing to pay, a single axis system or a double axis system can be installed. The benefit of having a dual axis system is that this allows the panels to following the sun both across the sky during the day, as well as during the seasons (Patel, 2006, p170-176).

Overall, solar cells provide a way in which solar energy can be converted into electricity. The efficiency with which a cell is able to do the design of the cell, the intensity of the sun, and the angle at which a solar panel is tilted with respect to the sun. Higher efficiency cells tend to cost more than lower efficiency cells making them less affordable.

Wind Energy

Another type of alternative energy that has attracted interest in the past is power harnessed from the wind. Wind power is almost completely renewable, the only fossil fuels used in the production of wind power come from the production, transportation, and upkeep (oil lubricants) of wind towers.

Wind technology offers several benefits over more traditional, fossil fuels, but it also features many drawbacks.

One of the biggest advantages wind power has over traditional energy technologies is the way in which it generates power. Wind turbines create power by turning the kinetic energy of the wind into mechanical energy, which is in turn used to produce electricity. First, wind flows over the blades causing them to lift and rotate. This in turn turns the rotor, which turns a low speed shaft. The low speed shaft is connected to a gear box which translates the low speed rotations of the wind turbine into high speed rotations of another shaft, which in turn is used to drive a generator, thus producing fossil fuel free electricity. This is advantageous because it uses a renewable source of energy that does not generate any type of emission ("How wind turbines," 2010).

Other parts seen in the diagram below, such as the pitch and yaw, are used to control the location of the blades with respect to wind currents, depending on wind speed and other factors. This is important for two specific reasons. First, this data can be used to optimize the performance of the wind turbine. Second, it can also be used to prevent the turbine from operating in dangerous conditions which may cause damage to the system.

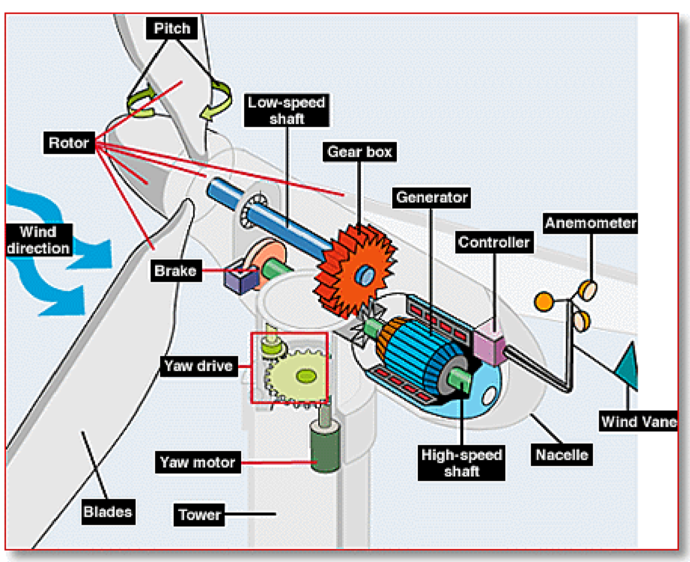


Figure 3: Typical Wind Turbine("How wind turbines," 2010)

Although the idea of producing energy with no emissions makes wind power sound very enticing, there are also several technically negative aspects of wind power to discuss. First, since wind farms need to be located in areas with acceptable wind speeds, new transmission lines will generally be required to connect new wind farms to the energy grid because state legislature generally requires wind farms to be located some distance away from people (Wiser, & Bolinger, 2010, p 60). Installing these new transmission lines can be expensive, although some studies claim that the benefits reaped from these new transmission lines would greatly outweigh the negatives ("Green power transmission,").

Another issue detrimental to the usage of wind power is its inability to easily provide constant power output. Wind speeds are not constant, and as such the power output by systems harnessing this energy is not constant either. Although improvements in technology have allowed for this issue to be slightly alleviated, it still presents a large limiting factor to the potential of wind energy. Another potential problem with wind energy is that increases in energy production per tower have been leveling off recently due to many different factors, including a mitigation of the increases of turbine height and rotor size (Wiser, & Bolinger, 2010, p 48-49).

The following chart shows acceptable wind turbine locations in colors other than white, with orange being the worst and blue being the best wind speed.

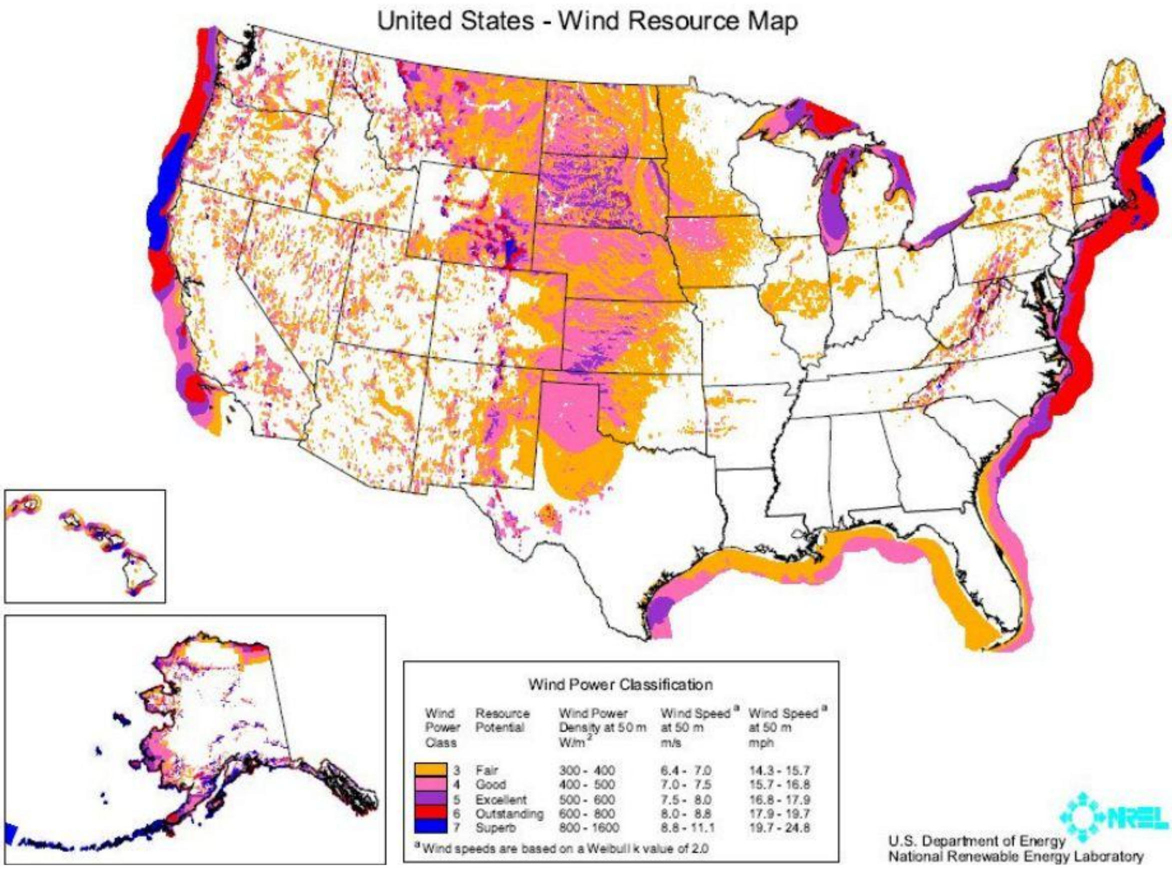


Figure 4 Wind speeds in the USA ("Wind energy basics," 2009)

An example of a typical industrial wind turbine is the GE 1.5 MW Turbine Series. The hub of one of these turbines sits 80 or 100 meters in the air and has a rotor diameter of 82.5 meters. The cut-in and cut-out speeds of these two turbines are 3.5 m/s and 25m/s wind speed respectively.

Below is the power curve for this series wind turbine ("GE power &," 2010).

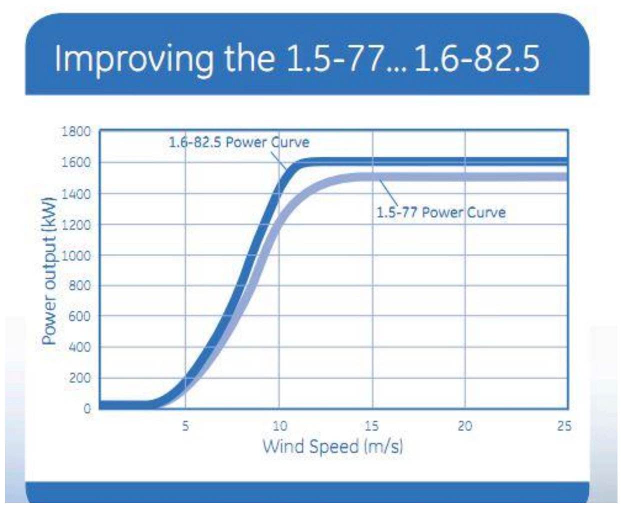


Figure 5 GE 1.5 MW turbine power curve ("Ge power &," 2010)

An example of a system more comparable to the 100kW Bloom Box is the 100kW Blue Sky turbine. This wind turbine is between 100 and 130 feet tall at the hub with a rotor diameter of about 65.52 feet ("Blue sky turbine," 2008).

In its simplest form the power that a turbine can potentially harvest is governed by the following equation:

$$P = \frac{1}{2}\rho V^3$$

Where P is power, ρ is air density, and V is the wind velocity (Patel, 2006, p. 25). From this equation it can be seen why wind velocity is so important when evaluating potential wind farm locations, since power is a function of velocity cubed.

Technologically there are several tradeoffs to contemplate when choosing and designing wind turbines. First size must be taken into account as larger turbines cost less per megawatt of potential, but they are more susceptible to producing less energy when used in a farm because downtime on one turbine can result in much more power being lost. Another aspect to consider is the number of blades on the turbine; a three turbine system compared to a two turbine system produces only about 5% more power but adds 50% blade weight and cost. Wind turbines can be operated either upwind or downwind. Upwind produces more power, but must continuously be yawed into the wind. Downwind turbines do not require a yaw mechanism, but generally do not produce as much power (Patel, 2006, p.76-79). Overall, a well-placed wind farm can be expected to output 30-40% of its rated power yearly (Nersesian, 2007, p 312).

Technical Conclusions

When comparing fuel cells, wind, and solar power, there are several important factors to note. First, a Bloom Box still requires some sort of fuel to be operated. This fuel is some type of hydrocarbon so unless said hydrocarbon is biogas, the system still adds net CO_2 to the atmosphere. Second, wind and solar power are not able to produce constant levels of electricity. This means that they cannot be depended on to provide continuous electricity and some form of backup generation must be installed to compensate for these systems. Lastly, due to their variable nature, wind and solar systems of 100kW do not provide the same amount of power as a 100kW Bloom Box.

From these arguments several conclusions can be drawn. Each system is dependent on different factors that limit where they can be placed. Wind systems must be located in an area that has high average wind speeds for optimal productivity. Similarly solar systems must be located in areas with high solar radiation intensity. A Bloom Box must be located someplace where it can receive some type of hydrocarbon fuel. This can be limited by natural gas lines or local laws if it were to be hooked up to a hydrocarbon holding tank. This means that although each system can be located in any part of the country, different areas are better suited to each system than another. For example, wind turbines do not generally work well in cities due to legislature where both Bloom Boxes and solar panels can be used.

Another important point to make is that due to the variable nature of solar and wind power, a Bloom Box will generally displace more CO_2 than a solar system or wind system of the same size. Larger solar and wind systems could produce the same amount of energy without producing any CO_2, but this would cost more money. Since the Bloom Box does produce CO_2 when run off of anything but biogas, it cannot be considered completely green after production.

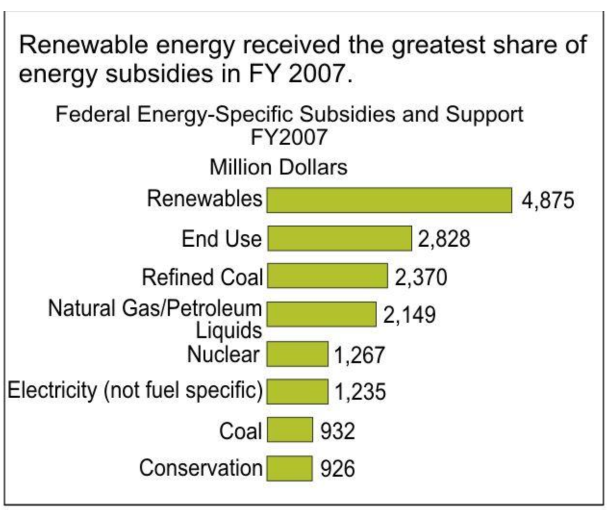
Overall, at least technically speaking, which system is the best is greatly dependent on where a company is located. It is also dependent on what the exact electrical needs of a consumer are. If the electricity must be constant, such as at a hospital, then a solar system or wind system would not be a wise main electrical system. If said system were powering someone’s home though, where they are not always using electricity, these systems could potentially be a more suitable choice for electricity production than a Bloom Box.

An Economic Comparison

In addition to the technical analysis of the Bloom Box, an analysis of the economics behind the technology needs to be examined. The technology could be sound but if the product is unmarketable due to expense, marketing trouble, or other logistical factors, than the product will not be a success. In order for a new product to be successful it needs to be both technically and economically viable. One without the other is useless. The following sections will analyze the Bloom Box, and Bloom Energy's business ideas evaluating the economics for the customer, Bloom Energy, and the governments supporting the technology, as well as compare some of Bloom's return on investment with other common alternative energy sources such as wind and solar power.

Government Subsidies for Energy Production

Government subsidies are an important aspect of all energy producing technologies. In the United States most, if not all, energy producers are subsidized in some manner as seen below. U.S. subsidies are provided by both the federal government and each individual state government. Subsidies are defined as "a transfer of Federal Government resources to the buyer or seller of a good or service"



Source: Energy Information Administration, *Federal Financial Interventions and Subsidies in Energy Markets 2007* (April 2008).

Rankings of subsidies and support based on absolute amount and amounts per megawatthour of generation differ widely, reflecting substantial differences in the amount of generation across fuels.

Subsidies and Support to Electric Production by Selected Primary Energy Sources

Primary Energy Source	FY 2007 Net Generation (billion kilowatthours)	Subsidies and Support Allocated to Electric Generation (million FY 2007 dollars)	Subsidies and Support per Unit of Production (dollars/megawatthour)
Natural Gas and Petroleum Liquids	919	227	0.25
Coal	1,946	854	0.44
Hydroelectric	258	174	0.67
Biomass	40	36	0.89
Geothermal	15	14	0.92
Nuclear	794	1,267	1.59
Wind	31	724	23.37
Solar	1	174	24.34
Refined Coal	72	2,156	29.81

Energy Information Administration, *Federal Financial Interventions and Subsidies in Energy Markets 2007*, SR/CNEAF/2008-1 (Washington, DC, 2008).

by the Department of Energy ("How much does," 2008). Subsidies can affect prices in several different manners including a reduction of price paid, an increase in the price received, or a reduction in the cost of production. These subsidies can be applied in several different manners including tax credits, monetary grants, and low interest loans. The purpose of these subsidies is to help a new technology into a market until the product is able to be produced and sold at a price competitive with established technologies in the market. From 1999 to 2007 subsidies allowed wind energy to increase at a rate of 32% a year on average, whereas other subsidized technologies such as coal and natural gas stayed fairly steady ("How much does," 2008).

From the charts above, it can be seen that subsidies for renewable sources are much larger in general than those provided for fossil fuels. It should be noted though that the numbers presented are subsidies as well as support given by the Federal Government, not just direct subsidies.

One question that always arises is whether or not the Federal Government should subsidize energy production. People who argue for subsidization argue that these subsidies help allow an industry to develop and grow. They argue that specifically in the energy industry investments are large risks and subsidies mitigate this problem allowing for more investment into energy programs, which in turn helps accelerate the subsidized programs. The American Wind Energy Association argued that:

"the $1.2 billion spent on nuclear energy in 2007 led to zero megawatts (MW) installed.
- the $3 billion spent on coal led to about 1,400 MW installed (without carbon reduction or storage, since that is not yet commercially viable).
- the $800 million spent on renewables (not including hydro) in 2007 led to about 6,000 MW installed. Of that, the $724 million provided to wind led to over 5,200 MW of new, zero-emissions, fuel-free generating capacity—35% of the ENTIRE new power generating capacity added in the country that year." ("Should the us," 2008)

These numbers present an enticing argument as to why government subsidies are useful, but it must be considered that the numbers cited when compared with the information provided by the DEA, appears to be the amount allocated for subsidy and support, meaning that this money may have been intended to not increase capacity but reduce emissions in the case of coal and toxic waste in the case of nuclear energy. Other's claim that by helping alternative energy industries the government can help reduce the countries' reliance on foreign oil. As seen by the graphic in the introduction to this paper though, only 1% of the nation's electricity was produced using oil. This means that unless the industries subsidized are able to help replace gasoline vehicles, this point is not particularly valid ("Should the us," 2008)

Others argue that government subsidies are not a worthwhile investment into the energy industry. One argument is that government subsidies allow companies to gain profit without truly benefiting anyone. This argument is a double edged sword though because although it is true that in a purely free market, people are more likely to pursue an idea only if it seems extremely promising, yet sometimes it is the crazy ideas that work out. For example, it is well known that although tap water is much cheaper than bottled water, many people still prefer bottled water over tap water. When companies for bottled water first started appearing many people scoffed at the idea. Another argument from Ben Lieberman and Nicholas D. Loris of the Thomas A. Roe Institute for Economic Policy Studies at the Heritage Foundation is:

"Federal efforts to pick winners and losers among energy sources—and to lavish mandates and subsidies on the perceived winners—have a dismal track record relative to allowing market forces to decide the direction of energy innovation." ("Should the us," 2008)

This idea suggests plainly that the government is not able to effectively predict the trends of the energy industry and thus invests in poor technology which only succeeds in any sense because of the government backing. Other arguments include the idea that in almost any other sector of business private investors will back a technology or product if it actually is a competitive product, and that government subsidies are a resignation that a technology is not wanted by private investors and thus is not worthwhile. Lastly, many feel it important to note that a product is only viable if it is able to compete without subsidies and thus they lack function.

When comparing the arguments of both sides, as well as the definition of a subsidy given by the DOE, it becomes apparent that problems between the two sides lie in two key areas, the purpose and use of subsidies. Given all this information it is the group's belief that when use moderately and with responsibility subsidies can be a positive influence, but they must not be thrown out to any technology with a remote possibility of being beneficial. In each of the following sections the subsidies pertaining to different technologies as well as examples of the cost of each product is discussed

The Bloom Box

As of now the cost of a Bloom Box is unavailable, but numerous sources including Bloom list the price at somewhere between $700,000 and $800,000 although one source, Green Tech Media, says that price is actually over one million dollars and the $700,000 to $800,000 is only after federal incentives are applied (Kanellos, 2011). Current Federal subsidies for commercial fuel cells are for a 30% discount up to $1500/kW off the initial cost. This would drop the cost to somewhere between $490,000 and $560,000. Additionally for the state of California where Bloom Boxes are presently being sold, $2500/kW is available at the time of purchase if the fuel cell is being run on natural gas or a $4,500/kW rebate is available if the fuel cell is being run on biogas or directed biogas. For the most part the option of running a Bloom Box on biogas will be ignored because pricing and availability of biogases are unavailable. However Adobe has been running their twelve Bloom Boxes on directed biogas and is claiming to be producing electricity for eight and a half cents per kilowatt hour (St. John, 2011). This number will be used for an estimation of the return on investment for a Bloom Box running on biogas.

If federal subsidies are applied to the cost of a Bloom Box then best case scenario the price can be reduced from $700,000 to $490,000 per unit. Since this price is possible in any state it will be used to calculate the current return on investment in states with unknown or no state level subsidies, and the maximum incentive will be included for states with additional programs that will subsidize the cost of fuel cells. For example California, where almost all of the Bloom Boxes have been installed so far, $2,500/kW is subsidized by the state for fuel cells running on natural gas. The results of this analysis are shown in chart F. Adobe is included as a separate entity because it is the only company that has publicly announced they are using directed biogas and what it is costing them to operate their fuel cells. The option of selling excess electricity back to the grid is not included because most states will not force utility companies to buy electricity from companies, and laws governing the resale of electricity often vary within states. In twelve of the forty three states with available data the customer's savings would match their initial investment within the ten year warranty as long as they ran their Bloom Box at it maximum capacity all the time. With state subsidies added, customers in California have a reduced cost to around $240,000. This price results in a return on investment in California of less than three years for the average rates, or if running the fuel cell on a renewable fuel, such as adobe has done, then the return on investment can be reduced to less than one year due to increased subsidies. Other states are not as lucky with seven states having an average net loss producing electricity with a Bloom Box, and an additional five taking over fifty years to match their initial investment.

If the same analysis is performed for industrial customers then the results are as shown in chart G. As the chart shows the return on investment for industrial users is not that good. In only six states will the average consumer match their initial investment within the ten year warranty, and twenty one have a return on investment greater than fifty years. This is due to significantly lower average electricity rates for industrial consumers with a few exceptions. Ironically industrial consumers are the most likely to need and use three phase 480V electricity.

To properly evaluate the economics of purchasing a Bloom Box the price of $700,000 with no additional subsidies will be considered. The results gathered from this assumption should then represent a best case, without the federal or state government supporting the technology. Additionally since Bloom Energy has not lowered its price in the past two years this will likely be the price going forward and moving out of dependence on government subsidies. Analyzing the Bloom Box under these conditions should present an unbiased review of the technology behind the Bloom Box from a strictly economic perspective.

By taking the information provided by Bloom Energy, and using state average natural gas, and electricity rates the return on investment can be found. Chart B uses the prices for commercial users on a state by state basis to calculate the return on investment. As the chart clearly shows, the average commercial business would not save enough money to match their initial investment for at least twenty six years. However for a company with a minimum electric load of 100kW, they could see a return on investment in as little as three years in Hawaii or ten years in California. In total, eight states out of the forty four with enough information available would match the initial investment within ten years, one of which is Massachusetts. Additionally since these numbers have been found using average prices other companies may be able to get a short return on investment provided the cost of natural gas is low enough and/or that the cost of electricity is high enough that the Bloom Box would save the company a minimum of eight cents per kilowatt hour.

For the average industrial customer the return on investment tends to be even worse due to the fact that industrial customers tend to enjoy lower electricity prices than commercial customers. This makes the average savings much lower and often nonexistent. As shown in chart C there are only nine states where the average industrial customer would have a return on investment within ten years, and in seventeen the customer would be losing money by using a Bloom Box. When the situation with a 100kW minimum load is tested, then in only four states can the average industrial consumer have a positive return on investment within ten years. This is because most industrial consumers have more than a 100kw average load, and the initial calculation would require the Bloom Box producing more power than it is capable of producing, allowing more savings in the same amount of time and a faster return on investment. As this is impossible it is more likely that the adjusted numbers are more accurate and the Bloom Box would only have a reasonable chance with industrial companies in four states.

For a residential analysis for an individual house sized unit some assumptions need to be made. Currently Bloom Energy only sells its Bloom Boxes in 100kW sized units, and few if any homes would need that much power. To examine the Bloom Box's potential for homeowners Bloom Energy's future estimations are used. Bloom Energy has stated that they plan to be selling a home appropriate unit in 2015 for about $3,000. Using that price the return on investment has been calculated for homeowners in each state. As chart A shows, in some states such as Alaska and Hawaii customers would save money equal to their initial investment within four years. In others such as Alabama or North Carolina the customer would never be able to repay their investment as it would cost customers in those states more to produce electricity from a Bloom Box than they currently pay. Overall the Bloom Box appears to be able to offer a return on investment within its warranty of ten years in 19 of the 50 states, including California and Massachusetts. The data also takes into account each state's average usage by residential customers to convert the return on investment into a time for the average residential customer. However this assumes that the person with the Bloom Box is getting 100% of its energy from a single Bloom Box. The average house will not have a constant power draw, so the Bloom Box will either be over producing (and possibly selling electricity back to the grid) or under producing and the customer is buying electricity from the grid. The problem with relying on selling back to the grid is that depending on the area power companies may or may not be mandated to purchase the excess electricity produced.

In addition to the economic aspects of installing a Bloom Box, the fact remains that if installed on a large scale, the Bloom Box would represent a significant change in how electricity is distributed to customers. Currently the majority of electricity is produced at power plants and then transferred to consumers through transmission lines. The main drawbacks to this system are the power losses that occur during transmission and the ability for the transmission system to be easily interrupted. Bloom Energy has proposed that if Bloom Boxes were to replace the electric grid as the primary source of electricity then a distributed generation system would emerge. This system would produce electricity where it would be consumed using Bloom Boxes. This system would essentially eliminate transmission line losses, and would be far less likely to get disrupted by weather. The main advantage that the current electric grid has over this new system is the fact that by transmitting electricity from the same sources to numerous consumers, as different electric loads either increased or decreased in one area the size of the system would still keep the average load fairly consistent. The fact that a Bloom Box cannot load follow means to have one as the sole source of electricity would require a unit that would constantly produce more electricity than the peak demand would reach. A far more likely scenario is that a combination of the two systems will emerge, to have the advantages of both by providing a stable power supply for the consumers' base electricity needs, and an interconnecting system that could balance the needs not met by the Bloom Box.

The Bloom Electron^{SM} Service

On January 20, 2011 Bloom Energy announced a new program known as the Bloom Electron Service. The Bloom Electron Service is a program that has customers purchase the electricity from the Bloom Box, instead of purchasing the box and running it to produce electricity. The customer allows Bloom Energy to install a Bloom Box on their property and hook it up to their power supply. In return the customer can lock in a flat rate for the electricity they buy from Bloom for 5-20% less than they currently pay for electricity. The goal is to "allow immediate cost savings with no initial investment, making onsite clean, reliable, affordable energy more accessible." ("Bloom energy announces," 2011) The Bloom Electron program represents a significant change in Bloom's business strategy and warrants extensive investigation.

For now the Bloom Electron Service is limited to the state of California. This is likely due to the government subsidies available there. Additionally the way the program works is first Bloom Electrons, an independent company purchases the Bloom Boxes from Bloom Energy. Then Bloom Electrons sets up the units and sells electricity to the actual customers. The reason behind this seems to be to allow Bloom Energy to take full advantage of the subsidies. If Bloom Energy did not sell the units first then there would not be subsidies available to them. By selling the Bloom Box to another company, they are able to get reimbursed for 30% of the cost from the federal government and $2500/kW from the government of California (Boudway, 2011). This means that when selling a single Bloom Box at an estimated cost of $1,000,000, $300,000 is reimbursed by the federal government and $250,000 from the state of California. This results in a final estimated cost of $450,000. The result is Bloom Energy/Bloom Electrons have an initial overhead of less than half the actual cost. This should half the time for a return on investment for the company. For the return on investment Bloomberg New Energy Finance has calculated that a Bloom Box produces electricity for about $0.14/kilowatt hour over ten years. They have also calculated that with long term natural gas contracts and federal and state incentives, that cost could be lowered to $0.07/kilowatt hour. Using the average cost of electricity to commercial customers in California ($0.14), and the published benefit of 5-20% lower electricity costs, Bloom Electrons is likely making a 3-6 cent profit per kilowatt hour (Kanellos, 2011). By combining this information in chart D, the different possible conditions under which the program could be operating, (or some combination thereof) are shown. The estimated cost of the ten year warranty has been added to the total cost as a rough and likely high estimate of the cost of repairs and maintenance over the ten year contract.

The chart displays a various number of boxes that represent different sized installments, with the range of likely profit margins per kilowatt hour. From the chart it is easy to see the distinct lack of profits that this plan appears to produce. The question then is why Bloom Energy has decided to initiate this program. The first option is one they themselves have implied. By offering this program they have provided companies a way to reduce their electricity bill with no initial investment and virtually no work. Thus the Bloom Electron program would serve to get Bloom's foot in the door of the energy market. Ten years down the line when the contracts come up for renewal, the companies using Bloom Boxes now will be very likely to want to continue to use them. At that point Bloom may have improved its fuel cell to produce power for significantly less than it currently can, and/or the price of electricity will have risen and Bloom can adjust the price it charges accordingly. This relies on two important assumptions, the first being that the Bloom Box can last ten years and still be in good working order, and the second, that Bloom Energy as a company has survived as a business under this capital intensive program which has had $100 million already invested by Credit Suisse Group and Silicon Valley Bank (Boudway, 2011).

That brings up an important consideration. Bloom Energy will not be the company trying to make money over the ten year contract. Bloom Electrons, an independent company is purchasing the units from Bloom Energy. So Bloom Energy is getting an instant return on investment with orders for hundreds of units already (200 units initially deployed) likely generating a huge profit for its shareholders ("Bloom energy announces," 2011). Assuming the price to be around $1,000,000 per unit since that will max out the amount paid by federal subsidies, then Bloom Energy has likely made around $200 million total profits. If these trends continue, and companies in California have no incentive to not join this program, then Bloom Energy will continue making a nice profit although Bloom Electrons will be hard pressed to make a profit in the immediate future.

Solar Energy

In 2009 603 megawatts of solar energy were installed in the United States ("U.s. electric net," 2010). The federal government provides a 30% tax exemption to residential, commercial, and industrial solar installations ("Residential renewable energy," 2011) ("Business energy investment," 2010). In California solar systems 100kW in size are eligible for a ₵39/kWh of produced energy incentive for the first five taxable years that they are installed. This incentive is paid in monthly installments ("California solar initiative," 2011). Smaller solar panels that would likely be installed for individual houses are eligible to receive a $2.50 per watt incentive driving the price down considerably. In 2005 the city of Oakland installed a 100kW system for $800,000. Half of this was paid for by California's SGIP, but this incentive no longer applies to solar systems ("Historic landmark gains," 2005).

In the field of solar energy there are many proponents and many opponents. Proponents argue that the cost of manufacturing PV cells has been steadily falling and thus the electricity provided by them has become increasingly competitive with electricity produced by fossil fuels.

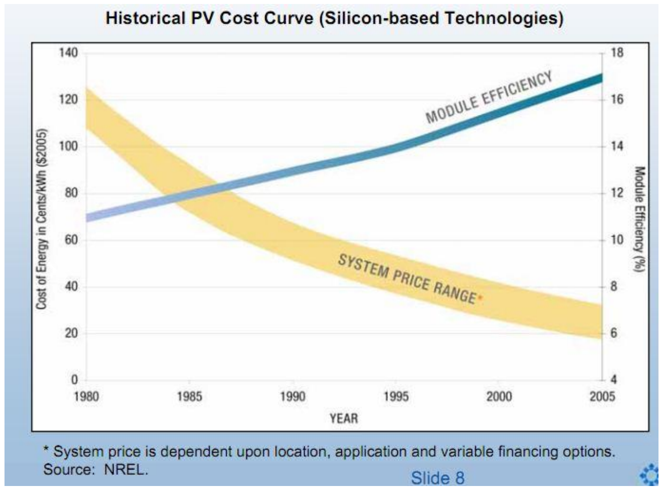


Figure 6 PV cost taken from source (Margolis, 2009)

Proponents also claim that realistically 10% of the United States electricity consumption could come from solar energy in 2025. Estimates also claim that the price of electricity could be 5₵/kwh if taken from concentrated solar power (CSP).

Opponents of solar energy offer several counter arguments. First they claim that photovoltaic cells are simply too inefficient to ever be considered a serious replacement for current electricity production. It has also been estimated that it takes a PV cell three years just to offset the energy that was made in producing the solar cell itself. They also claim that although CSP systems can be cheaper that PV systems they still require government subsidies to be competitive with non-renewable energy sources ("Is solar power," 2009).

Economically there are several points to consider in the solar technology. First, solar panels are currently fairly expensive. Government incentives can help alleviate this problem and trends suggest that prices for these systems should continue to decrease over time. Currently though it is hard to argue that, at least economically, everybody should be buying solar panels. For people who can afford them they appear to be a nice product, but they currently do not stand as some amazing solution to energy problems, mainly because of high prices, and intermittent performance.

Wind Energy

In 2009, total wind power installations were greater than 35000MW in the United States. In 2009 9994MW of new wind energy production was added at a price of $21 billion. This equates to about $2.1 million dollars per a MW of wind energy installed. This installation accounted for thirty-nine percent of the total new electricity production in the United States in 2009 (Wiser, & Bolinger, 2010, p. 3). One company sells a 100KW system, the same size as a Bloom Box, for $495000 ("Blue sky turbine," 2008).

In 2009 the average price of energy from wind turbines was about $51/MWh (Wiser, & Bolinger, 2010, p 39). Current federal incentives for wind power are 2.2₵/kWh. This incentive is currently set to expire for sites installed after December 31, 2012. For sites that do meet the date for the credit, the general runtime of the incentive is 10 years ("Renewable electricity production," 2010). For a small business using a 100Kw or smaller turbine for power a federal tax exemption credit is also available. This credit states that any system of acceptable size placed before December 31, 2016 is 30% tax deductible, thus the $495,000 wind turbine discussed above would only cost $346,500 to buy and have installed ("Business energy investment," 2011). In different states additional subsidies can be applied as well. For example in California, assuming that funding is available, one can receive an additional subsidy of $1.50/W, meaning that the 100Kw turbine would cost a California buyer $196,500("Self-generation incentive program," 2010). In Massachusetts wind turbines used privately are property tax exempt for 20 years and systems smaller than 99kW can receive additional incentives (“Masscec – commonwealth,” 2006).

There are some critics of wind power. These people cite issues such as the noise of a wind turbine and their effects on birds. Although wind turbines are generally quiet, they are able to produce large amounts of noise. For example, a larger turbine can produce 100 dB of ambient sound, which is equivalent to a train. This sound only reaches lower levels after about 1 mile. Another problem with wind turbines is electromagnetic interference that they may cause. The actual nature of interference depends on a lot of characteristics such as the proximity of the turbine to an EMF emitter, physical and electrical characteristics of the tower, etc. This issue can be so severe that in the United Kingdom five offshore wind farms were cancelled due to the interference they may have caused with communication systems at nearby airfields. Another often cited issue with wind turbines is their propensity to kill birds. This was true in the 1980s when poorer technologies meant faster moving turbine blades, and may have resulted in as many as 5,000,000 bird deaths each year. That number has declined though due to improvements in technology allowing for longer, slower moving turbine blades. Regardless of improvements in technology though, the 5,000,000 bird deaths is a skewed number when the amount of other direct or indirect man related deaths are considered. It has been estimated that 121 million birds and one billion birds are killed each year by hunters and glass window collisions, respectively. Protections from placing wind turbines in the paths of migratory birds and nesting grounds can make receiving permission to erect wind turbines and farms somewhat arduous, but the threat that wind power poses to birds is much smaller than typically advertised (Nersesian, 2007, p. 312-313).

Monetarily wind power is fairly cheap compared to a similarly sized Bloom Box or solar system. A wind system is subject to government subsidies which help lower the price for the purchaser, by shifting the cost to taxpayers. Wind power does present several problems though as previously discussed. Overall, though, the low price of an installed wind system, at least compared to the Bloom Box and solar systems, make it an attractive idea for people who live in appropriate locations.

Economic Conclusions

When comparing the Bloom Box, wind power and solar power there are several observations to be made. First, the initial investment for a Bloom Box is equivalent to a comparable solar system at about 800 thousand dollars per 100kWs installed. A Wind turbine is generally cheaper at 495 thousand dollars per 100kws installed. This means that for actual required capital a wind turbine is the most affordable. It must be taken into consideration though that a Bloom Box generates electricity at a constant rate, unlike either a wind turbine or a solar panel.

It can also be noted that each of these technologies is eligible to receive a large incentive from the Federal Government. This incentive, which is 30% of the cost of the product, drives the price down significantly in each case. State subsidies in California further increase the amount of money that the customer will ultimately not have to pay. In the case of wind and the Bloom Box, this incentive can be directly subtracted from the cost to buy the product, thus reducing the initial price. Solar incentives are more difficult to deal with in California because they depend on the amount of energy produced for a 100kW sized system. These actual implications of these numbers are discussed later in the cost comparison section as well as the paper's overall conclusion.

Cost Comparison

Using Chart H for reference, several comparisons of different technologies in a California setting and a Massachusetts setting can be observed. First we can see that federal and state subsidies pay for a significant amount of each of the fuel cell, wind turbine, and solar cell 100kW installment in each case. Also it can be observed that although each system is 100kW, the expected output of each system is vastly different. The expected solar panel output is found using a typical cell efficiency and statistics of the amount of solar radiation that hits a square meter of land per day in the given area. The wind turbine's expected output is found using the expected power output of a wind turbine in a good location, which is about 35% of the rated capacity. The reason the typical wind speed of an area cannot be used is that a wind turbine's output power is not linear with speed, and thus will not simply average out to the power output of the average wind speed.

As for deciding which product is the best, it really depends on what a person is trying to optimize for. It can be seen that although the Bloom fuel cell produces CO_2, because it typically generates much more electricity it still offsets more CO_2 in a year than either wind or solar power would if the displaced power were instead produced by natural gas combustion. Also, the Bloom fuel cell saves a person more money a year than either wind or solar power does.

When it comes to the direct monetary return on investment (ROI), the decision as to which system may be the best becomes much more difficult to analyze, mainly due to the unknown price of a Bloom Box. It is also unknown whether the given price ranges for a Bloom Box of 700-800 thousand dollar is before or after the inclusion of government subsidies. When both situations are taken into account, the effect of government and state (in the case of California) becomes clear. Assuming the price of a Bloom Box is $800,000 before any sort of government subsidy, the ROI is approximately 3.5 years run on natural gas and about .6 years on subsidized directed biogas, both of which compare favorably to both wind and solar technologies. When Bloom's subsidies are removed, their product becomes a much longer investment than wind technology, but not solar. If All subsidies are removed, then once again the Bloom Box appears to have an advantage in ROI.

Conclusions

To determine the implications of the Bloom Energy Server as a whole, the individual aspects of the technical, economic, and social implications must be considered together. Additionally it needs to be compared to other equivalent renewable technologies.

From a technical standpoint the Bloom Box appears to perform as claimed. It contains some improvements to the basic SOFC design, and can achieve efficiencies higher than typical coal and natural gas power plants. As stated in the technical information section, Bloom Energy has some advantages over other fuel cell companies, primarily that they have been increasing their production rate over the past two years, and have a method to guarantee a continuous level of performance as the fuel cell ages. Going forward, other companies could easily have a better product than Bloom Energy.

When similar technologies are competing one variable that can determine the value of one product compared to another is the price. Price can not only be a determining factor in what product people buy but also who the product is available to. The cost of a 100 kW Bloom Box has been previously stated to be between $700,000 and $800,000. This initial price is much higher than that for an equivalent wind turbine installed which from one distributer costs 495 thousand dollars. This price is comparable to an equivalent installation of solar panels, which in 2005 cost the city of Oakland roughly 800 thousand dollar to have installed before any federal or state incentives. It is important to remember that a Bloom Box is able to produce constant electricity twenty four hours a day, seven days a week, unlike either solar or wind technologies. Although the Bloom Box costs significantly more, depending on a customer's particular needs it could certainly be a wiser investment than either 100 kW of wind or solar power.

On the other hand, a Bloom Box requires a constant supply of fuel, meaning it not only has a higher initial cost than wind, it also has an operating cost that is not present in either wind or solar electricity generation systems. In order to take this into account, the return on investment in each technology was considered. As previously discussed in the cost comparison section, the average ROI of an unsubsidized Bloom Box in California is slightly sooner than a wind turbine if run on natural gas, but much longer if it is being run on directed biogas. In both cases the unsubsidized Bloom Box has a better ROI than solar power. From a strictly monetary point of view, a Bloom Box appears to be the best option for commercial customers seeking to reduce their carbon footprint.

Another important economic aspect to consider when analyzing energy technologies is federal and state government subsidies. Applied subsidies can greatly reduce initial costs to the consumer allowing for much quicker ROI. As previously stated, subsidies allow a Bloom Box in California run on directed biogas to quickly save a customer money compared to all other analyzed technologies.

Since the Bloom Energy Corporation only sells their servers within the state of California and has not announced any plans to change this, it is rather difficult to suggest the Bloom Box monetarily to any companies outside of California. Companies that operate within the state of California, however, appear to have a product worth considering; assuming current subsidy levels remain in place.

Overall the Bloom Box has potential as an alternative energy source for businesses as long as the current levels of subsidies remain in place. Additionally the Bloom Electrons Service is an extremely beneficial program for consumers, but the economics of the current system do not seem profitable over the long term for Bloom Electrons, although it is providing Bloom Energy with an immediate profit. From a technical standpoint a Bloom Box seems to have an advantage over traditional generators if cost is not considered. It produces less noise and fewer pollutants than a traditional generator due to the fact that it operates at a higher efficiency. It has some advantages over alternative systems such as solar and wind generators, and in some cases is preferable to solar or wind systems. Although the Bloom Box still produces emissions when run on natural gas, it still appears advantageous over solar and wind systems in place. The carbon neutral nature of running a Bloom Box on biogas cannot be taken into account because of the current availability of biogas. The major question is if Bloom Energy can reduce the cost of a Bloom Box to a reasonable amount without the government subsidizing over 67% of the cost, which in turn is passed on to electricity companies (who pass the cost on to customers) and taxpayers. However considering the cost has remained static for the past two years despite improvements in production, and the recent suspension of state subsidies in California, the Bloom Box does not seem to be likely to have a significant impact without additional improvements to the technology.

Appendices

Chart A: Return on Investment by State for Residential Customers

State	$/kWh (BB) AVG	Energy Grid $/kWh	Bloom Box Savings $/kWh	Bloom Box Savings $/month	Return on Investment Months	Return on Investment Years
Alabama	0.11	0.10	-0.01	-7.63	Never	Never
Alaska	0.05	0.17	0.12	77.55	38.7	3.2
Arizona	0.10	0.10	0.00	1.85	1620.4	135.0
Arkansas	0.09	0.09	0.01	7.88	380.6	31.7
California	0.07	0.14	0.07	38.90	77.1	6.4
Colorado	0.06	0.10	0.04	27.79	108.0	9.0
Connecticut	0.10	0.20	0.09	67.10	44.7	3.7
Delaware	0.10	0.14	0.04	39.58	75.8	6.3
District of Columbia	0.10	0.13	0.03	19.93	150.5	12.5
Florida	0.13	0.12	-0.01	-14.91	Never	Never
Georgia	0.11	0.10	-0.01	-10.55	Never	Never
Hawaii	0.22	0.33	0.10	64.28	46.7	3.9
Idaho	0.07	0.07	0.00	0.38	7916.8	659.7
Illinois	0.07	0.11	0.04	32.31	92.8	7.7
Indiana	0.07	0.09	0.01	14.89	201.5	16.8
Iowa	0.07	0.09	0.02	19.34	155.1	12.9
Kansas	0.08	0.09	0.01	9.94	301.8	25.2
Kentucky	0.08	0.08	0.00	-3.31	Never	Never
Louisiana	0.09	0.10	0.02	19.02	157.7	13.1
Maine	0.11	0.16	0.06	29.36	102.2	8.5
Maryland	0.09	0.14	0.04	45.50	65.9	5.5
Massachusetts	0.11	0.18	0.07	43.83	68.5	5.7
Michigan	0.07	0.11	0.04	25.13	119.4	9.9
Minnesota	0.07	0.10	0.03	23.92	125.4	10.5
Mississippi	0.08	0.10	0.02	24.48	122.5	10.2
Missouri	0.08	0.08	0.00	-2.95	Never	Never
Montana	0.07	0.09	0.03	21.11	142.1	11.8
Nebraska	0.07	0.08	0.01	12.03	249.5	20.8
Nevada	0.08	0.12	0.04	34.77	86.3	7.2
New Hampshire	0.10	0.16	0.06	33.93	88.4	7.4
New Jersey	0.09	0.16	0.07	49.61	60.5	5.0
New Mexico	0.07	0.10	0.03	18.10	165.8	13.8
New York	0.10	0.18	0.09	51.21	58.6	4.9
North Carolina	0.10	0.10	0.00	-2.74	Never	Never
North Dakota	0.06	0.08	0.01	13.24	226.6	18.9
Ohio	0.08	0.10	0.02	14.72	203.8	17.0
Oklahoma	0.08	0.09	0.02	16.75	179.1	14.9
Oregon	0.09	0.08	0.00	-1.74	Never	Never
Pennsylvania	0.09	0.11	0.02	16.07	186.7	15.6
Rhode Island	0.10	0.17	0.07	42.22	71.1	5.9
South Carolina	0.10	0.10	0.00	-1.09	Never	Never
South Dakota	0.07	0.08	0.02	15.26	196.7	16.4
Tennessee	0.08	0.09	0.01	6.89	435.2	36.3
Texas	0.08	0.13	0.05	59.28	50.6	4.2
Utah	0.06	0.08	0.02	17.83	168.2	14.0
Vermont	0.10	0.14	0.05	28.88	103.9	8.7
Virginia	0.10	0.10	0.00	0.15	20074.8	1672.9
Washington	0.08	0.08	-0.01	-6.16	Never	Never
West Virginia	0.09	0.07	-0.02	-21.30	Never	Never
Wisconsin	0.07	0.12	0.04	28.62	104.8	8.7
Wyoming	0.06	0.08	0.02	17.06	175.8	14.7

Chart B: Return on Investment by State for Commercial Customers

	$/kWh (BB)	Energy Grid	Bloom Box Savings		Return on Investment		ROI	1 box runtime
State	AVG	$/kWh	$/kWh	$/month	Months	Years	kWh	Years
Alabama	0.05	0.10	0.05	236.05	2965.5	247.1	15008370	17
Alaska	0.03	0.14	0.10	514.32	1361.0	113.4	6875898	8
Arizona	0.04	0.09	0.05	420.16	1666.0	138.8	14036268	16
Arkansas	0.04	0.08	0.03	175.10	3997.8	333.1	22147752	25
California*	0.04	0.13	0.08	467.38	1497.7	124.8	8634236	10
Colorado	0.04	0.09	0.05	223.13	3137.2	261.4	14929739	17
Connecticut	NA	0.17	NA	NA	NA	NA	NA	NA
Delaware	NA	0.12	NA	NA	NA	NA	NA	NA
District of Columbia	0.04	0.13	0.09	2197.67	318.5	26.5	7981452	9
Florida	0.04	0.10	0.06	436.44	1603.9	133.7	11033110	13
Georgia	0.05	0.09	0.04	313.65	2231.8	186.0	16039809	18
Hawaii	0.05	0.30	0.25	1178.92	593.8	49.5	2807917	3
Idaho	0.04	0.06	0.01	67.95	10301.7	858.5	52446079	60
Illinois	0.03	0.12	0.09	651.33	1074.7	89.6	7903485	9
Indiana	0.05	0.08	0.03	186.83	3746.6	312.2	22487364	26
Iowa	NA	0.07	NA	NA	NA	NA	NA	NA
Kansas	0.04	0.07	0.04	209.66	3338.7	278.2	19471231	22
Kentucky	0.03	0.07	0.04	238.62	2933.5	244.5	16239901	19
Louisiana	NA	0.10	NA	NA	NA	NA	NA	NA
Maine	0.04	0.13	0.09	342.89	2041.5	170.1	8041376	9
Maryland	0.05	0.13	0.08	794.75	880.8	73.4	9124051	10
Massachusetts	0.05	0.16	0.11	652.99	1072.0	89.3	6249683	7
Michigan	0.05	0.09	0.04	263.72	2654.4	221.2	16619000	19
Minnesota	0.04	0.08	0.04	255.46	2740.1	228.3	19084969	22
Mississippi	0.03	0.10	0.07	344.78	2030.3	169.2	9976727	11
Missouri	NA	0.07	NA	NA	NA	NA	NA	NA
Montana	0.04	0.09	0.04	164.95	4243.8	353.6	17000529	19
Nebraska	0.05	0.07	0.02	88.29	7928.2	660.7	40782813	47
Nevada	0.05	0.10	0.06	280.29	2497.4	208.1	12676892	14
New Hampshire	0.04	0.14	0.10	382.77	1828.8	152.4	6687789	8
New Jersey	NA	0.14	NA	NA	NA	NA	NA	NA
New Mexico	NA	0.09	NA	NA	NA	NA	NA	NA
New York	0.04	0.17	0.13	818.78	854.9	71.2	5344167	6
North Carolina	0.10	0.08	-0.02	-140.92	-4967.3	Never	Never	Never
North Dakota	0.07	0.07	0.00	20.32	34444.8	2870.4	226543617	259
Ohio	0.08	0.09	0.01	50.06	13983.7	1165.3	90013121	103
Oklahoma	0.08	0.08	0.00	13.72	51030.3	4252.5	305926937	349
Oregon	0.09	0.07	-0.01	-76.02	-9208.3	Never	Never	Never
Pennsylvania	0.09	0.09	0.00	-4.92	-142351.0	Never	Never	Never
Rhode Island	0.10	0.15	0.05	287.37	2435.9	203.0	13436456	15
South Carolina	0.10	0.08	-0.02	-84.78	-8257.0	Never	Never	Never
South Dakota	0.07	0.07	0.00	1.66	422731.5	35227.6	2297968541	2623
Tennessee	0.09	0.09	0.01	38.24	18307.8	1525.6	97470652	111
Texas	0.08	0.11	0.03	190.04	3683.5	307.0	24671919	28
Utah	0.06	0.07	0.01	44.38	15771.4	1314.3	117402663	134
Vermont	0.09	0.12	0.03	112.98	6195.5	516.3	21244416	24
Virginia	0.10	0.07	-0.02	-234.44	-2985.9	Never	Never	Never
Washington	0.08	0.07	-0.01	-84.63	-8271.0	Never	Never	Never
West Virginia	0.09	0.06	-0.03	-129.55	-5403.2	Never	Never	Never
Wisconsin	0.08	0.09	0.02	99.86	7010.0	584.2	41099510	47
Wyoming	0.06	0.07	0.00	20.27	34531.4	2877.6	214094585	244

Chart C: Return on Investment by State for Industrial Customers

	$/kWh (BB)	Energy Grid	Bloom Box Savings		Return on Investment		ROI	1 box runtime
State	AVG	$/kWh	$/kWh	$/month	Months	Years	kWh	Years
Alabama	0.05	0.06	0.01	2257.24	310.1	25.8	97648692	111
Alaska	0.04	0.14	0.10	8677.84	80.7	6.7	6694006	8
Arizona	0.04	0.07	0.02	3658.41	191.3	15.9	28056014	32
Arkansas	0.05	0.06	0.01	572.99	1221.7	101.8	54729054	62
California	0.05	0.10	0.05	2994.63	233.8	19.5	12855395	15
Colorado	0.04	0.07	0.03	2326.84	300.8	25.1	26311768	30
Connecticut	NA	0.15	NA	NA	NA	NA	NA	NA
Delaware	NA	0.10	NA	NA	NA	NA	NA	NA
District of Columbia	0.05	0.10	0.06	116388.06	6.0	0.5	11772189	13
Florida	0.04	0.08	0.04	3053.29	229.3	19.1	16170469	18
Georgia	0.05	0.07	0.02	2885.18	242.6	20.2	41238727	47
Hawaii	0.05	0.26	0.21	99232.00	7.1	0.6	3322947	4
Idaho	0.05	0.04	0.00	-27.96	-25034.9	Never	Never	Never
Illinois	0.03	0.05	0.01	8663.23	80.8	6.7	50929659	58
Indiana	0.05	0.05	0.01	1245.97	561.8	46.8	125227394	143
Iowa	NA	0.05	NA	NA	NA	NA	NA	NA
Kansas	0.04	0.06	0.02	770.03	909.1	75.8	41707583	48
Kentucky	0.03	0.05	0.02	9841.76	71.1	5.9	43435918	50
Louisiana	NA	0.08	NA	NA	NA	NA	NA	NA
Maine	0.04	0.12	0.07	6744.40	103.8	8.6	9712440	11
Maryland	0.05	0.10	0.05	2781.66	251.6	21.0	13567343	15
Massachusetts	0.05	0.15	0.10	5564.56	125.8	10.5	6954510	8
Michigan	0.05	0.07	0.02	3407.40	205.4	17.1	43555300	50
Minnesota	0.04	0.06	0.02	3322.28	210.7	17.6	45956737	52
Mississippi	0.03	0.07	0.03	6256.00	111.9	9.3	20414679	23
Missouri	NA	0.05	NA	NA	NA	NA	NA	NA
Montana	0.05	0.06	0.01	1291.80	541.9	45.2	53971614	62
Nebraska	0.05	0.05	0.00	17.40	40241.1	3353.4	791462687	903
Nevada	0.05	0.08	0.03	10436.92	67.1	5.6	21408155	24
New Hampshire	0.04	0.13	0.09	4611.51	151.8	12.6	7614140	9
New Jersey	NA	0.11	NA	NA	NA	NA	NA	NA
New Mexico	NA	0.06	NA	NA	NA	NA	NA	NA
New York	0.04	0.10	0.06	8762.65	79.9	6.7	11135736	13
North Carolina	0.10	0.06	-0.05	-9968.58	-70.2	Never	Never	Never
North Dakota	0.07	0.06	-0.01	-1514.27	-462.3	Never	Never	Never
Ohio	0.09	0.06	-0.03	-5989.82	-116.9	Never	Never	Never
Oklahoma	0.08	0.06	-0.02	-1435.10	-487.8	Never	Never	Never
Oregon	0.09	0.05	-0.04	-1776.11	-394.1	Never	Never	Never
Pennsylvania	0.10	0.07	-0.03	-4025.21	-173.9	Never	Never	Never
Rhode Island	0.10	0.14	0.04	1626.75	430.3	35.9	18830630	21
South Carolina	0.10	0.05	-0.05	-26613.93	-26.3	Never	Never	Never
South Dakota	0.07	0.05	-0.02	-1168.17	-599.2	Never	Never	Never
Tennessee	0.09	0.06	-0.03	-33642.10	-20.8	Never	Never	Never
Texas	0.08	0.09	0.01	341.76	2048.2	170.7	112112291	128
Utah	0.06	0.05	-0.02	-1321.53	-529.7	Never	Never	Never
Vermont	0.10	0.09	0.00	-1778.80	-393.5	Never	Never	Never
Virginia	0.10	0.06	-0.04	-12223.21	-57.3	Never	Never	Never
Washington	0.08	0.05	-0.04	-2512.97	-278.6	Never	Never	Never
West Virginia	0.09	0.04	-0.05	-5090.23	-137.5	Never	Never	Never
Wisconsin	0.08	0.07	-0.01	-5617.14	-124.6	Never	Never	Never
Wyoming	0.07	0.04	-0.02	-1864.88	-375.4	Never	Never	Never

Chart D: Analysis of Bloom Electron Service[SM]

Bloom Electron Service Analysis										
# 0f Boxes	Profit Margin	$/hr	cost no warranty	Net Profit 10ys	Net Profit 20ys	Total cost	Net Profit 10ys	Net Profit 20ys	Avg 10yrs	Avg 20yrs
1	0.03	3	325000	-62200	600	525000	-262200	-199400	-162200	-99400
1	0.04	4	325000	25400	175800	525000	-174600	-24200	-74600	75800
1	0.05	5	325000	113000	351000	525000	-87000	151000	13000	251000
1	0.06	6	325000	200600	526200	525000	600	326200	100600	426200
1	0.07	7	325000	288200	701400	525000	88200	501400	188200	601400
1	0.08	8	325000	375800	876600	525000	175800	676600	275800	776600
# 0f Boxes	Profit Margin	$/hr	cost no warranty	Net Profit 10ys	Net Profit 20ys	Total cost	Net Profit 10ys	Net Profit 20ys	Avg 10yrs	Avg 20yrs
5	0.03	15	1625000	-311000	3000	2625000	-1311000	-997000	-811000	-497000
5	0.04	20	1625000	127000	879000	2625000	-873000	-121000	-373000	379000
5	0.05	25	1625000	565000	1755000	2625000	-435000	755000	65000	1255000
5	0.06	30	1625000	1003000	2631000	2625000	3000	1631000	503000	2131000
5	0.07	35	1625000	1441000	3507000	2625000	441000	2507000	941000	3007000
5	0.08	40	1625000	1879000	4383000	2625000	879000	3383000	1379000	3883000
# 0f Boxes	Profit Margin	$/hr	cost no warranty	Net Profit 10ys	Net Profit 20ys	Total cost	Net Profit 10ys	Net Profit 20ys	Avg 10yrs	Avg 20yrs
11	0.03	33	5225000	-2334200	-1643400	7425000	-4534200	-3843400	-3434200	-2743400
11	0.04	44	5225000	-1370600	283800	7425000	-3570600	-1916200	-2470600	-816200
11	0.05	55	5225000	-407000	2211000	7425000	-2607000	11000	-1507000	1111000
11	0.06	66	5225000	556600	4138200	7425000	-1643400	1938200	-543400	3038200
11	0.07	77	5225000	1520200	6065400	7425000	-679800	3865400	420200	4965400
11	0.08	88	5225000	2483800	7992600	7425000	283800	5792600	1383800	6892600
# 0f Boxes	Profit Margin	$/hr	cost no warranty	Net Profit 10ys	Net Profit 20ys	Total cost	Net Profit 10ys	Net Profit 20ys	Avg 10yrs	Avg 20yrs
21	0.03	63	12327000	-6808200	-5489400	16527000	-11008200	-9689400	-8908200	-7589400
21	0.04	84	12327000	-4968600	-1810200	16527000	-9168600	-6010200	-7068600	-3910200
21	0.05	105	12327000	-3129000	1869000	16527000	-7329000	-2331000	-5229000	-231000
21	0.06	126	12327000	-1289400	5548200	16527000	-5489400	1348200	-3389400	3448200
21	0.07	147	12327000	550200	9227400	16527000	-3649800	5027400	-1549800	7127400
21	0.08	168	12327000	2389800	12906600	16527000	-1810200	8706600	289800	10806600

Subsidies				
# of boxes	cost/box	Federal	Warrenty	total cost
1	1000000	375000	200000	525000
5	5000000	1875000	1000000	2625000
11	11000000	2475000	2200000	7425000
21	21000000	2373000	4200000	16527000

Chart E: Bloom Box Data Sheet

Technical Highlights	
Inputs	
Fuels	Natural Gas, Directed Biogas
Input fuel pressure	15 psig
Fuel required @ rated power	0.661 MMBtu/hr of natural gas
Water required (for startup only)	120 gallons municipal water
Outputs	
Rated power output (AC)	100 kW
Electrical efficiency (LHV net AC)	> 50%
Electrical connection	480V @ 60 Hz, 4-wire 3 phase
Physical	
Weight	10 tons
Size	224" x 84" x 81"
Emissions	
NOx	< 0.07 lbs/MW-hr
SOx	negligible
CO	< 0.10 lbs/MW-hr
VOCs	< 0.02 lbs/MW-hr
CO2 @ specified efficiency	773 lbs/MW-hr on natural gas, carbon neutral on Directed Biogas
Environment	
Standard temperature range	0° to 40° C (extreme weather kit available)
Max altitude at rated power	6,000 ft. MSL
Humidity	20% - 95%
Seismic Vibration	IBC site class D
Location	Outdoor
Noise @ rated power	< 70 DB @ 6 feet
Codes and Standards	
Complies with Rule 21 interconnection standards	
Exempt from CA Air District permitting; meets stringent CARB 2007 emissions standards	
Product Listed by Underwriters Laboratories Inc. (UL) to ANSI/CSA America FC 1	
Additional Notes	
Operates in a grid parallel configuration	
Includes a secure website for you to showcase performance & environmental benefits	
Remotely managed and monitored by Bloom Energy	
Capable of emergency stop based on input from your facility	

Chart F: Return on Investment by State for Commercial Customers after Federal Subsidies

	$/kWh (BB)	Energy Grid	Bloom Box Savings		Return on Investment		ROI	1 box runtime
State	AVG	$/kWh	$/kWh	$/month	Months	Years	kWh	Years
Alabama	0.05	0.10	0.05	236.05	2075.8	173.0	10505859	12.0
Alaska	0.03	0.14	0.10	514.32	952.7	79.4	4813128	5.5
Arizona	0.04	0.09	0.05	420.16	1166.2	97.2	9825388	11.2
Arkansas	0.04	0.08	0.03	175.10	2798.5	233.2	15503426	17.7
California	0.04	0.13	0.08	467.38	406.5	33.9	2343578	2.7
Adobe on Biogas	0.09	0.13	0.04	232.91	85.9	7.2	495050	0.6
Colorado	0.04	0.09	0.05	223.13	2196.0	183.0	10450817	11.9
Connecticut	NA	0.17	NA	NA	NA	NA	NA	NA
Delaware	NA	0.12	NA	NA	NA	NA	NA	NA
District of Columbia	0.04	0.13	0.09	2197.67	223.0	18.6	5587017	6.4
Florida	0.04	0.10	0.06	436.44	1122.7	93.6	7723177	8.8
Georgia	0.05	0.09	0.04	313.65	1562.2	130.2	11227867	12.8
Hawaii	0.05	0.30	0.25	1178.92	415.6	34.6	1965542	2.2
Idaho	0.04	0.06	0.01	67.95	7211.2	600.9	36712255	41.9
Illinois	0.03	0.12	0.09	651.33	752.3	62.7	5532439	6.3
Indiana	0.05	0.08	0.03	186.83	2622.7	218.6	15741154	18.0
Iowa	NA	0.07	NA	NA	NA	NA	NA	NA
Kansas	0.04	0.07	0.04	209.66	2337.1	194.8	13629862	15.6
Kentucky	0.03	0.07	0.04	238.62	2053.5	171.1	11367931	13.0
Louisiana	NA	0.10	NA	NA	NA	NA	NA	NA
Maine	0.04	0.13	0.09	342.89	1429.0	119.1	5628963	6.4
Maryland	0.05	0.13	0.08	794.75	616.5	51.4	6386835	7.3
Massachusetts	0.05	0.16	0.11	652.99	750.4	62.5	4374778	5.0
Michigan	0.05	0.09	0.04	263.72	1858.1	154.8	11633300	13.3
Minnesota	0.04	0.08	0.04	255.46	1918.1	159.8	13359478	15.3
Mississippi	0.03	0.10	0.07	344.78	1421.2	118.4	6983709	8.0
Missouri	NA	0.07	NA	NA	NA	NA	NA	NA
Montana	0.04	0.09	0.04	164.95	2970.6	247.6	11900370	13.6
Nebraska	0.05	0.07	0.02	88.29	5549.8	462.5	28547969	32.6
Nevada	0.05	0.10	0.06	280.29	1748.2	145.7	8873824	10.1
New Hampshire	0.04	0.14	0.10	382.77	1280.1	106.7	4681452	5.3
New Jersey	NA	0.14	NA	NA	NA	NA	NA	NA
New Mexico	NA	0.09	NA	NA	NA	NA	NA	NA
New York	0.04	0.17	0.13	818.78	598.5	49.9	3740917	4.3
North Carolina	0.10	0.08	-0.02	-140.92	-3477.1	Never	Never	Never
North Dakota	0.07	0.07	0.00	20.32	24111.4	2009.3	158580532	181.0
Ohio	0.08	0.09	0.01	50.06	9788.6	815.7	63009185	71.9
Oklahoma	0.08	0.08	0.00	13.72	35721.2	2976.8	214148856	244.5
Oregon	0.09	0.07	-0.01	-76.02	-6445.8	Never	Never	Never
Pennsylvania	0.09	0.09	0.00	-4.92	-99645.7	Never	Never	Never
Rhode Island	0.10	0.15	0.05	287.37	1705.1	142.1	9405519	10.7
South Carolina	0.10	0.08	-0.02	-84.78	-5779.9	Never	Never	Never
South Dakota	0.07	0.07	0.00	1.66	295912.1	24659.3	1608577979	1836.3
Tennessee	0.09	0.09	0.01	38.24	12815.5	1068.0	68229456	77.9
Texas	0.08	0.11	0.03	190.04	2578.4	214.9	17270343	19.7
Utah	0.06	0.07	0.01	44.38	11040.0	920.0	82181864	93.8
Vermont	0.09	0.12	0.03	112.98	4336.9	361.4	14871091	17.0
Virginia	0.10	0.07	-0.02	-234.44	-2090.1	Never	Never	Never
Washington	0.08	0.07	-0.01	-84.63	-5789.7	Never	Never	Never
West Virginia	0.09	0.06	-0.03	-129.55	-3782.3	Never	Never	Never
Wisconsin	0.08	0.09	0.02	99.86	4907.0	408.9	28769657	32.8
Wyoming	0.06	0.07	0.00	20.27	24172.0	2014.3	149866209	171.1

Chart G: Return on Investment by State for Industrial Customers after Federal Subsidies

	$/kWh (BB)	Energy Grid	Bloom Box Savings		Return on Investment		ROI	1 box runtime
State	AVG	$/kWh	$/kWh	$/month	Months	Years	kWh	Years
Alabama	0.05	0.06	0.01	2257.24	248.1	20.7	78118954	89
Alaska	0.04	0.14	0.10	8677.84	64.5	5.4	5355205	6
Arizona	0.04	0.07	0.02	3658.41	153.1	12.8	22444811	26
Arkansas	0.05	0.06	0.01	572.99	977.3	81.4	43783244	50
California	0.05	0.10	0.05	2994.63	187.0	15.6	10284316	12
Colorado	0.04	0.07	0.03	2326.84	240.7	20.1	21049414	24
Connecticut	NA	0.15	NA	NA	NA	NA	NA	NA
Delaware	NA	0.10	NA	NA	NA	NA	NA	NA
District of Columbia	0.05	0.10	0.06	116388.06	4.8	0.4	9417751	11
Florida	0.04	0.08	0.04	3053.29	183.4	15.3	12936375	15
Georgia	0.05	0.07	0.02	2885.18	194.1	16.2	32990982	38
Hawaii	0.05	0.26	0.21	99232.00	5.6	0.5	2658358	3
Idaho	0.05	0.04	0.00	-27.96	-20027.9	Never	Never	Never
Illinois	0.03	0.05	0.01	8663.23	64.6	5.4	40743727	47
Indiana	0.05	0.05	0.01	1245.97	449.4	37.5	100181915	114
Iowa	NA	0.05	NA	NA	NA	NA	NA	NA
Kansas	0.04	0.06	0.02	770.03	727.2	60.6	33366066	38
Kentucky	0.03	0.05	0.02	9841.76	56.9	4.7	34748735	40
Louisiana	NA	0.08	NA	NA	NA	NA	NA	NA
Maine	0.04	0.12	0.07	6744.40	83.0	6.9	7769952	9
Maryland	0.05	0.10	0.05	2781.66	201.3	16.8	10853874	12
Massachusetts	0.05	0.15	0.10	5564.56	100.6	8.4	5563608	6
Michigan	0.05	0.07	0.02	3407.40	164.3	13.7	34844240	40
Minnesota	0.04	0.06	0.02	3322.28	168.6	14.0	36765389	42
Mississippi	0.03	0.07	0.03	6256.00	89.5	7.5	16331743	19
Missouri	NA	0.05	NA	NA	NA	NA	NA	NA
Montana	0.05	0.06	0.01	1291.80	433.5	36.1	43177291	49
Nebraska	0.05	0.05	0.00	17.40	32192.9	2682.7	633170150	723
Nevada	0.05	0.08	0.03	10436.92	53.7	4.5	17126524	20
New Hampshire	0.04	0.13	0.09	4611.51	121.4	10.1	6091312	7
New Jersey	NA	0.11	NA	NA	NA	NA	NA	NA
New Mexico	NA	0.06	NA	NA	NA	NA	NA	NA
New York	0.04	0.10	0.06	8762.65	63.9	5.3	8908589	10
North Carolina	0.10	0.06	-0.05	-9968.58	-56.2	Never	Never	Never
North Dakota	0.07	0.06	-0.01	-1514.27	-369.8	Never	Never	Never
Ohio	0.09	0.06	-0.03	-5989.82	-93.5	Never	Never	Never
Oklahoma	0.08	0.06	-0.02	-1435.10	-390.2	Never	Never	Never
Oregon	0.09	0.05	-0.04	-1776.11	-315.3	Never	Never	Never
Pennsylvania	0.10	0.07	-0.03	-4025.21	-139.1	Never	Never	Never
Rhode Island	0.10	0.14	0.04	1626.75	344.2	28.7	15064504	17
South Carolina	0.10	0.05	-0.05	-26613.93	-21.0	Never	Never	Never
South Dakota	0.07	0.05	-0.02	-1168.17	-479.4	Never	Never	Never
Tennessee	0.09	0.06	-0.03	-33642.10	-16.6	Never	Never	Never
Texas	0.08	0.09	0.01	341.76	1638.6	136.5	89689833	102
Utah	0.06	0.05	-0.02	-1321.53	-423.8	Never	Never	Never
Vermont	0.10	0.09	0.00	-1778.80	-314.8	Never	Never	Never
Virginia	0.10	0.06	-0.04	-12223.21	-45.8	Never	Never	Never
Washington	0.08	0.05	-0.04	-2512.97	-222.8	Never	Never	Never
West Virginia	0.09	0.04	-0.05	-5090.23	-110.0	Never	Never	Never
Wisconsin	0.08	0.07	-0.01	-5617.14	-99.7	Never	Never	Never
Wyoming	0.07	0.04	-0.02	-1864.88	-300.3	Never	Never	Never

Chart H: Comparison of technologies Costs

						100 kW systems in California
Technology	Price	Federal Sub.	State Sub.	Price after	Percent Subsidized	fuel costs/year
Bloom Fuel Cell(Natural gas)	800000	240000	300000	260000	67.5	35040
Bloom Fuel Cell(directed Biogas)	800000	240000	540000	20000	97.5	74406.126
Bloom Fuel Cell(directed Biogas)800K	800000	0	240000	560000	Null	74406.126
Wind Turbine	495000	148500	150000	196500	60.3030303	0
Solar Panel	800000	240000	0	560000	30	0
						100 KW systems in Massachusetts
Technology	Price	Federal Sub.	State Sub.	Price after		fuel costs/year
Bloom Fuel Cell	800000	240000	0	560000	30	43800
Wind Turbine	495000	148500	0	346500	30	0
Solar Panel	800000	240000	0	560000	30	0

Expected Power Output/year(MW)	C02 Produced(lbs)	CO2 Offset(lbs)	Savings/Year	ROI(years)	ROI No subsidies
876	677148	798912	74460	3.491807682	10.74402364
876	Carbon Neutral	1476060	35093.874	0.569900034	22.79600138
876	Carbon Neutral	1476060	35093.874	15.95720096	Unknown
306.6	0	516621	38325	5.127201566	12.91585127
274.553	0	462621.805	34319.125	16.31743234	23.31061762

Expected Power Output/year(MW)	C02 Produced(lbs)	CO2 Offset(lbs)	Savings/Year	ROI(years)	ROI No subsidies
876	677148	798912	96360	5.811540058	8.302200083
306.6	0	516621	49056	7.063356164	10.09050881
152.5335	0	257018.9475	24405.36	22.94577912	32.77968446

Correspondence with the University of Tennessee

Mr Goodman: Unfortunately I cannot provide you the information you requested. The data will be compiled in a report to the sponsoring agency, the Office of Naval Research, at the end of the contract and released to the public by them after their review. Insofar as the emissions are concerned I believe the results of Bloom's air quality tests had to be reported to obtain the Californian Air Quality Standards Board approval and these should be a matter of public record. You'll have to go dig them out I'm afraid and you might try Google to start with. The University through a research proposal made to ONR by the SimCenter was awarded the funds to install a specific fuel cell, the Bloom unit, for evaluation of reliability, performance and emissions.

Henry McDonald

On Dec 10, 2010, at 8:31 PM, Goodman, Brian M wrote:

Dr Henry McDonald,

Thank you very much for the information you provided. I was wondering if you could possibly provide us with the recorded data for the natural gas in, electricity out, and quantity and type of emissions. Additionally, if it's not too much trouble a statement or explanation of why the university decided to install the bloom box. Again thank you for your help.

Sincerely,

Brian Goodman

From: Henry McDonald [mailto:Henry-McDonald@utc.edu]
Sent: Wednesday, December 01, 2010 6:57 AM
To: Goodman, Brian M
Subject: Re: Bloom Box Fuel Cell

Mr Goodman : There is not a great deal to tell - the unit has been operating continuously (24/7) since it was installed in March. It is operating at its rated power level of ~100Kw and an efficiency level of 49%. Here efficiency is based on energy equivalence of the natural gas in over the electrical power out. Emissions are well below the California State Air Quality Board Standards. All in all the unit is performing as advertised. We understand that that a 200Kw unit is entering limited service and is achieving 60% efficiency. The cost of power generated from the unit therefore hinges on the cost of natural gas and the capital cost of the equipment. Several installations purchase waste site gas which is input into the national distribution system and then they withdraw this amount of gas from their local line. This allows them to claim renewable power and get various tax credits for their investment. The unit can also run on various alcohol based fuels such as ethanol which can also allow the renewable energy tax incentive credits.

Henry McDonald

On Nov 30, 2010, at 10:30 PM, Goodman, Brian M wrote:

Dear Dr Henry McDonald,

Hello, my name is Brian Goodman and I am currently a Junior at Worcester Polytechnic Institute working on my Interactive Qualifying Project(IQP). The IQP is a project that challenges students to address a problem that lies at the intersection of science or technology with social issues and human needs. As Bloom Energy's new fuel cell has the potential to improve our electricity production, my group members and I are examining the technology behind the fuel cell and its potential impact on society. Since the University of Tennessee at Chattanooga recently installed a 100kW Bloom Energy Server and are monitoring it closely I was hoping that the University would be willing to assist us since we are located in Massachusetts and otherwise unable to personally monitor an energy server. Dr. Whitfield said that you were the person in charge of the fuel cell and would have the information we are looking for. If the University can and would be willing to provide us with any information it would be greatly appreciated. Thank you for any help you are able to offer.

Sincerely,

Brian Goodman

Electrical Engineering

WPI Class of 2012

Correspondence with Bloom Energy

From: Garrett Ruiz [Garrett.Ruiz@bloomenergy.com]
Sent: Monday, December 06, 2010 5:36 PM
To: Sanford, Thane W
Subject: RE: Questions for a student project

Dear Thane,

1.) This information is considered proprietary and confidential.
2.) Bloom Energy servers can be installed on hard flat surfaces capable of supporting their weight (10 tons). Bloom installs a concrete pad that the Energy Server sits on. All our Energy Servers are installed outdoors.
3.) While our systems are capable of running at reduced capacity for maintenance purposes, they are generally not designed to output less than their rated kW output of 100kW.
4.) That information is considered proprietary and confidential.
5.) Exact pricing is considered confidential and only shared with customers, but they generally cost between $700,000 and $800,000.
6.) Our vision to make clean, reliable energy affordable for everyone in the world. We have a ways to go, but are working with numerous partners to ensure that we one day have a product that can benefit people around the globe. Bloom's solid oxide fuel cell technology is inherently fuel flexible. Our systems can be designed to run on nearly any hydrocarbon - natural gas, propane, ethanol, biogas, diesel, or simply pure hydrogen.
7.) This information is considered proprietary and confidential.

I know that I have not provided you with a great deal of information, but due to the nature of our product, this is all I can give you at this time. Good luck on your project!

Kind Regards,

Garrett Ruiz
Marketing Coordinator
Tel: 408.543.1742
Cel: 408.386.5508
www.bloomenergy.com

1.) From watching interviews of K.R. Sridhar and reading newspaper
articles it seems that your product contains an internal steam reformer.
Can you either confirm or clarify on this? If your product does contain a steam reformer, we understand that the steam reforming process is energy consuming, have you taken steps to compensate for this?
2.) If a company is interested in purchasing a fuel cell what steps
need to be taken so Bloom Fuel Cell can be installed? I.E. On what surfaces can it be installed on? Can it be installed inside and if so does an indoor installation require any additional set up?
3.) Can the volume of fuel consumed by the fuel cell be varied in
order to vary the output power produced by the fuel cell?
4.) It has been indicated that the Bloom Fuel Cell is currently
being sold with a ten year warranty during which time your company will fix any problems that arise with the fuel cell. So far how frequently have the fuel cells required repair if at all?
5.) Would you be willing to provide us with the current selling cost

of a Bloom Box fuel cell?
6.) You have mentioned the potential for the Bloom Box to be used in
developing countries due to the advantage that the Bloom Box system does not require transmission line infrastructure. However, the fuel cell requires some type of fuel and transportation of fuel to the location of the fuel cell may be just as difficult or expensive. Can you enlighten us onto how the fuel cell would be cost effective in developing countries? Also what other alternative fuel can be used that may readily available to developing questions?
7.) Would it be possible for you to provide us with operational data
gathered from the Bloom Box such as input fuel and resultant power production or any other factors that may impact operation such as temperature, fuel pressure, load characteristics, etc.?

-----Original Message-----
From: Sanford, Thane W [mailto:dukes777@WPI.EDU]
Sent: Monday, December 06, 2010 1:36 PM
To: Garrett Ruiz
Subject: RE: Questions for a student project

Mr. Ruiz,

I was just wondering if you ever got those questions I sent you back in November regarding the Bloombox for my IQP? Any help would be very much appreciated.

Sincerely,

Thane Sanford
IMGD Art Major
Sigma Pi Member
WPI Class of 2012

____
From: Garrett Ruiz [Garrett.Ruiz@bloomenergy.com]
Sent: Tuesday, October 26, 2010 8:52 PM
To: Sanford, Thane W
Subject: RE: Questions for a student project

Dear Thane,

Thank you for your interest in Bloom Energy! Please accept our apologies for the delayed response. Know that our team has been working diligently to get back to everyone, and we certainly appreciate your patience.

Send me your questions and I will answer them the best that I can.

Kind Regards,
Garrett Ruiz

-----Original Message-----
From: Sanford, Thane W [mailto:dukes777@WPI.EDU]
Sent: Friday, October 08, 2010 5:53 PM

To: info
Subject: Questions for a student project

To whom it may concern:

My name is Thane Sanford and I'm currently a junior at Worcester Polytechnic Institute. As a junior, we are required to do an Independent Qualify Project (IQP). For my groups IQP, we are studying the Bloom Box and the social implications that come with it. I was wondering if there was somebody that would be willing to answer 3-5 questions for us on the subject. It would be much appreciated.

Sincerely,

Thane Sanford
IMGD Art Major
Sigma Pi Member
WPI Class of 2012

Bibliography

Alternative energy: the bloom box. (2010). [Web]. Retrieved from Alternative Energy: The Bloom Box

Brady, Jeff (2009, April 27th) An Aged Electric Grid Looks To A Brighter Future Retrieved from http://www.npr.org/templates/story/story.php?storyId=103327321

Ballantine, A.W; McElroy, J.F. (2010) U.S. Patent No. 7,833,668 Washington, DC: U.S. Patent and Trademark office; retrieved from: http://patft.uspto.gov/netacgi/nph-Parser?Sect1=PTO2&Sect2=HITOFF&u=%2Fnetahtml%2FPTO%2Fsearch-adv.htm&r=1&f=G&l=50&d=PTXT&p=1&p=1&S1=7,833,668&OS=7,833,668&RS=7,833,668

Barras, C. (2010, February 26). Innovation: bloom didn't start a fuel-cell revolution. Retrieved from http://www.newscientist.com/article/dn18584-innovation-bloom-didnt-start-a-fuelcell-revolution.html

Bloom energy solid oxide fuel cell . (n.d.). Retrieved from http://www.machine-history.com/Bloom%20Energy%20Solid%20Oxide%20Fuel%20Cell

Basic Failures by Ohio Utility Set Off Blackout, Report Finds (2003, November 20th) Retrieved from http://www.nytimes.com/2003/11/20/us/basic-failures-by-ohio-utility-set-off-blackout-report-finds.html

Bloom energy announces bloom electrons℠. clean, reliable, affordable energy without the initial expense. (2011, January 20). Retrieved from http://c0688662.cdn.cloudfiles.rackspacecloud.com/downloads-pdf-release-bloom-electrons-1-20-2011.pdf

Bloom Energy Announces Industry-Leading Customers (2010, February 24th) Retrieved from http://www.businesswire.com/news/home/20100224005647/en/Bloom-Energy-Announces-Industry-Leading-Customers

Bloom Energy: You pay for the juice, not the box (2011, January 20th). Retrieved from http://news.cnet.com/8301-11128_3-20029035-54.html

Blue sky turbine 100kw. (2008, December 04). Retrieved from http://www.planetturbine.com/blue-sky-turbine-100kw.html

Boudway, I. (2011, January 20). Bloom energy's fuel cell breakthrough. Retrieved from http://www.businessweek.com/technology/content/jan2011/tc20110120_212633.htm

Business energy investment tax credit (itc). (2010, June 09). Retrieved from http://www.dsireusa.org/incentives/incentive.cfm?Incentive_Code=US02F&re=1&ee=1

California solar initiative - pv incentives. (2011, January 10). Retrieved from http://www.dsireusa.org/incentives/incentive.cfm?Incentive_Code=CA134F&re=1&ee=1

Can alternative energy effectively replace fossil fuels?. (2009, October 26). Retrieved from http://alternativeenergy.procon.org/view.answers.php?questionID=001244

Ceres power. (n.d.). Retrieved from http://www.cerespower.com/
Ceres Power Holdings plc, . (2010). Ceres power commences residential chp field trials in consumers' homes.

Chp product demonstration at ceres power's corporate headquarters. (2010). [Web]. Retrieved from http://www.cerespower.com/InvestorRelations/PresentationsandVideos/CHPProductDemonstration/ /

Clean energy. (2007, December 27). Retrieved from http://www.epa.gov/cleanenergy/energy-and-you/affect/air-emissions.html

Company overview. (n.d.). Retrieved from http://www.cerespower.com/AboutUs/CompanyOverview

Doggett, S. (2010, March 05). Maker of touted 'bloom box' fuel cell faces doubts on costs, pace of production [Web log message]. Retrieved from http://blogs.edmunds.com/greencaradvisor/2010/03/maker-of-touted-bloom-box-fuel-cell-faces-doubts-on-costs-pace-of-production.html

Eia- electricity data, analysis, surveys. (2010, November 23). Retrieved from http://www.eia.doe.gov/cneaf/electricity/epa/epa_sum.html

Es-5000 energy server. (2010). Retrieved from http://www.bloomenergy.com/products/data-sheet/

Ge power & water renewable energy 1.5 mw wind turbine series. (2010). Retrieved from http://www.gepower.com/prod_serv/products/wind_turbines/en/downloads/GEA14954C15-MW-Broch.pdf

Green power transmission and consumer savings. (n.d.). Retrieved from http://awea.org/learnabout/publications/loader.cfm?csModule=security/getfile&PageID=4133

Gottmann, M; McElroy J.F; Mitlitsky, F; Sridhar, K.R. (2009) U.S. Patent No. 7,572,530 Washington, DC: U.S. Patent and Trademark office; retrieved from: http://patft.uspto.gov/netacgi/nph-Parser?Sect1=PTO2&Sect2=HITOFF&u=%2Fnetahtml%2FPTO%2Fsearch-adv.htm&r=1&f=G&l=50&d=PTXT&p=1&p=1&S1=7,572,530&OS=7,572,530&RS=7,572,530

Hansen, J. B; Dahl, S (2010) Patent No. 20064382 Oslo, Norway: Norwegian Patent Office retrieved from: http://worldwide.espacenet.com/publicationDetails/biblio?DB=EPODOC&adjacent=true&locale=en_EP&FT=D&date=20101213&CC=DK&NR=1768207T3&KC=T3

Hickey, D; Karuppaiah, C; McElroy J. (2009) U.S. Patent No. 7,514,166 Washington, DC: U.S. Patent and Trademark office; retrieved from: http://patft.uspto.gov/netacgi/nph-Parser?Sect1=PTO2&Sect2=HITOFF&u=%2Fnetahtml%2FPTO%2Fsearch-adv.htm&r=2&f=G&l=50&d=PTXT&p=1&p=1&S1=7,514,166&OS=7,514,166&RS=7,514,166

Hickey, D; Russel, I. (2006) U.S. Patent No. 7,150,927 Washington, DC: U.S. Patent and Trademark office; retrieved from: http://patft.uspto.gov/netacgi/nph-Parser?Sect1=PTO2&Sect2=HITOFF&u=%2Fnetahtml%2FPTO%2Fsearch-adv.htm&r=4&f=G&l=50&d=PTXT&p=1&p=1&S1=7,150,927&OS=7,150,927&RS=7,150,927

Historic landmark gains 100kw solar pv system. (2005, May 23). Retrieved from http://www.renewableenergyworld.com/rea/news/article/2005/05/historic-landmark-gains-100-kw-solar-pv-system-30733

History of alternative energy. (2010). Retrieved from http://www.benefits-of-recycling.com/historyofalternativeenergy.html

History of Geothermal Energy (2008) Retrieved from http://www.top-alternative-energy-sources.com/history-of-geothermal-energy.html

History of wind energy. (2005, September 12). Retrieved from http://www1.eere.energy.gov/windandhydro/wind_history.html

How much does the federal government spend on energy-specific subsidies and support?. (2008, September 08). Retrieved from http://tonto.eia.doe.gov/energy_in_brief/energy_subsidies.cfm

How wind turbines work. (2010, September 01). Retrieved from http://www1.eere.energy.gov/windandhydro/wind_how.html

Is solar power an economical alternative to conventional energy?. (2009, February 25). Retrieved from http://alternativeenergy.procon.org/view.answers.php?questionID=001311

Kanellos, M. (2011, January 20). Bloom energy's fuel cells-as-a-service: do the economics work?. Retrieved from http://www.greentechmedia.com/articles/read/bloom-energys-fuel-cells-as-a-service-do-the-economics-work/

Levan, M. D; Finn, J. E; McElroy J. F. (2009) U.S. Patent No. 7,591,880 Washington, DC: U.S. Patent and Trademark office; retrieved from: http://patft.uspto.gov/netacgi/nph-Parser?Sect1=PTO2&Sect2=HITOFF&u=%2Fnetahtml%2FPTO%2Fsearch-adv.htm&r=1&f=G&l=50&d=PTXT&p=1&p=1&S1=7,591,880&OS=7,591,880&RS=7,591,880

Lyngby, . (2010, June 28). Topsoe fuel cell sofc stacks are sea bound. Retrieved from http://www.topsoefuelcell.com/sitecore/content/Topsoe_fuel_cell/news_and_info/press_releases/010710.aspx

Margolis, R.M. (2009). Solar energy: market trends and dynamics. Proceedings of the NARUC 2009 Winter Committee Meeting, retrieved from: http://www.narucmeetings.org/Presentations/Solar_RobertMargolis_2009.pdf

Masscec - commonwealth wind incentive program – micro wind initiative. (2010, August 06). Retrieved from http://www.dsireusa.org/incentives/incentive.cfm?Incentive_Code=MA22F&re=1&ee=1

McElroy, J.F; Finn, J.E. (2007) U.S. Patent No. 7,201,979 Washington, DC: U.S. Patent and Trademark office; retrieved from:http://patft.uspto.gov/netacgi/nph-Parser?Sect1=PTO2&Sect2=HITOFF&u=%2Fnetahtml%2FPTO%2Fsearch-adv.htm&r=5&f=G&l=50&d=PTXT&p=1&p=1&S1=7,201,979&OS=7,201,979&RS=7,201,979

McElroy, J.F; Sridhar, K.R. (2007) U.S. Patent No. 7,255,956 Washington, DC: U.S. Patent and Trademark office; retrieved from:http://patft.uspto.gov/netacgi/nphParser?Sect1=PTO2&Sect2=HITOFF&p=1&u=%2Fnetahtml%2FPTO%2Fsearch-bool.html&r=2&f=G&l=50&co1=AND&d=PTXT&s1=7255956&OS=7255956&RS=7255956

McElroy, J.F; Sridhar, K.R; Finn, J.E; Mitlitsky, F; Gottmann, M. (2009) U.S. Patent No. 7,482,078 Washington, DC: U.S. Patent and Trademark office; retrieved from: http://patft.uspto.gov/netacgi/nph-Parser?Sect1=PTO2&Sect2=HITOFF&u=%2Fnetahtml%2FPTO%2Fsearch-adv.htm&r=5&f=G&l=50&d=PTXT&p=1&p=1&S1=7482078&OS=7482078&RS=7482078

Milestones. (n.d.). Retrieved from http://www.topsoefuelcell.com/about_us/milestones.aspx

Morain, D. (2011, February 20). Green energy firm finds gold in the halls of power. The Sacramento Bee, Retrieved from http://www.sacbee.com/2011/02/20/3414791/green-energy-firm-finds-gold-in.html

Morgan, R; Devriendt, J; Leah, R. (2007) Patent No. 2436396 Newport, South Wales: U.K. Intellectual Property Office; retrieved from: http://worldwide.espacenet.com/publicationDetails/biblio?DB=EPODOC&adjacent=true&locale=en_EP&FT=D&date=20070926&CC=GB&NR=2436396A&KC=A

Nasa™ technology comes to earth. (n.d.). Retrieved from http://www.bloomenergy.com/about/company-history/

Nersesian, R.L. (2007). Energy for the twenty-first century. United States : M E Sharpe Inc.

Nielsen, P.E.H; Joensen, F; Soerensen, E.L. (2010) Patent No. 2010149339 Geneva, Switzerland: World Intellectual Property Organization ; retrieved from http://worldwide.espacenet.com/publicationDetails/biblio?DB=EPODOC&adjacent=true&locale=en_EP&FT=D&date=20101229&CC=WO&NR=2010149339A1&KC=A1

Nielsen, K. A; Linderoth, S; Hendriksen, P. V; Persson, A; Mikkelsen, L; Christiansen, N; Larsen, J.G. (2010) Patent No. 20092513 Oslo, Norway: Norwegian Patent Office; retrieved from: http://worldwide.espacenet.com/publicationDetails/biblio?FT=D&date=20101202&DB=EPODOC&locale=en_EP&CC=AU&NR=2010241468A1&KC=A1

Niles, Raymond C. (2008) Property Rights and the Crisis of the Electric Grid retrieved from http://www.theobjectivestandard.com/issues/2008-summer/property-rights-electric-grid.asp

Patel, M.R. (2006). Wind and solar power systems: design, analysis, and operation. Boca Raton , FL: CRC. (R., 2006)

Price charts. (n.d.). Retrieved from http://www.platinum.matthey.com/pgm-prices/price-charts/

Projects. (n.d.). Retrieved from http://www.topsoefuelcell.com/business_areas/micro_chp/projects.aspx

Renewable electricity production tax credit (ptc). (2010, May 04). Retrieved from http://www.dsireusa.org/incentives/incentive.cfm?Incentive_Code=US13F&re=1&ee=1

Residential renewable energy tax credit. (2011, February 03). Retrieved from http://www.dsireusa.org/incentives/incentive.cfm?Incentive_Code=US37F&re=1&ee=1

Self-generation incentive program. (2011, March 01). Retrieved from http://www.dsireusa.org/incentives/incentive.cfm?Incentive_Code=US13F&re=1&ee=1

Should the us subsidize alternative energies?. (2008, December 02). Retrieved from http://alternativeenergy.procon.org/view.answers.php?questionID=001251

Solar Energy HISTORY (2006) Retrieved from http://www.facts-about-solar-energy.com/solar-energy-history.html

Sridhar, K.R; Gottmann, M. (2008) U.S. Patent No. 7,364,810 Washington, DC: U.S. Patent and Trademark office; retrieved from:http://patft.uspto.gov/netacgi/nph-Parser?Sect1=PTO2&Sect2=HITOFF&u=%2Fnetahtml%2FPTO%2Fsearch-adv.htm&r=6&f=G&l=50&d=PTXT&p=1&p=1&S1=7,364,810&OS=7,364,810&RS=7,364,810

Srinivasan, R; Gurunathan, R. (2010)) U.S. Patent No. 7,705,490 Washington, DC: U.S. Patent and Trademark office; retrieved from: http://patft.uspto.gov/netacgi/nph-Parser?Sect1=PTO2&Sect2=HITOFF&u=%2Fnetahtml%2FPTO%2Fsearch-adv.htm&r=2&f=G&l=50&d=PTXT&p=1&p=1&S1=7,705,490&OS=7,705,490&RS=7,705,490

Steele, B.C.H (2004) G.B. Patent No. 2394114 (A) Newport, South Wales: U.K. Intellectual Property Office; retrieved from:http://worldwide.espacenet.com/publicationDetails/biblio?CC=GB&NR=2394114A&KC=A&FT=D&date=20040414&DB=EPODOC&locale=en_EP

Steele, B.C.H; Gehe, L; Naoki, O; Ahmet, S (2006) Patent No. 2400486 Newport, South Wales: U.K. Intellectual Property Office; retrieved from: http://worldwide.espacenet.com/publicationDetails/biblio?DB=EPODOC&adjacent=true&locale=en_EP&FT=D&date=20061025&CC=ZA&NR=200508144A&KC=A

St. John, J. (2011, January 25). How green are bloom electrons? depends on the gas. Retrieved from http://gigaom.com/cleantech/how-green-are-bloom-electrons-depends-on-the-gas/

The bloom energy bloom box - answering the unanswered questions. (2010, February 22). Retrieved from http://www.glgroup.com/News/The-Bloom-Energy-Bloom-Box---Answering-the-Unanswered-Questions-46756.html

The ceres cell. (n.d.). Retrieved from http://www.cerespower.com/Technology/TheCeresCell/
The Electric Power Transmission and Distribution Industry (2010) Retrieved from http://www.incontext.indiana.edu/2010/july-aug/article3.asp

Topsoe fuel cell. (n.d.). Retrieved from http://www.topsoefuelcell.com/

Topsoe milestones. (n.d.). Retrieved from http://www.topsoe.com/about_us/milestones_helside.aspx

U.S. Department of Energy, (2007). The potential benefits of distributed generation and rate-related issues that may impede their expansion Retrieved from http://www.ferc.gov/legal/fed-sta/exp-study.pdf
U.s. electric net summer capacity. (2010, August). Retrieved from http://www.eia.doe.gov/cneaf/alternate/page/renew_energy_consump/table4.html

Venkataraman, S. (2010) U.S. Patent No. 7,704,617 Washington, DC: U.S. Patent and Trademark office; retrieved from: http://patft.uspto.gov/netacgi/nph-Parser?Sect1=PTO2&Sect2=HITOFF&u=%2Fnetahtml%2FPTO%2Fsearch-adv.htm&r=1&f=G&l=50&d=PTXT&p=1&p=1&S1=7,704,617&OS=7,704,617&RS=7,704,617

Venkataraman, S; Finn, J.E; Mitlitsky, F; Gottmann, M. (2009) U.S. Patent No. 7,422,810 Washington, DC: U.S. Patent and Trademark office; retrieved fromhttp://patft.uspto.gov/netacgi/nph-Parser?Sect1=PTO2&Sect2=HITOFF&u=%2Fnetahtml%2FPTO%2Fsearch-adv.htm&r=4&f=G&l=50&d=PTXT&p=1&p=1&S1=7422810&OS=7422810&RS=7422810

Venkataraman, S; Lyle, W. D; Perry, M; Whittenberger, W (2009) U.S. Patent No. 7,524,572 Washington, DC: U.S. Patent and Trademark office; retrieved from: http://patft.uspto.gov/netacgi/nph-Parser?Sect1=PTO2&Sect2=HITOFF&u=%2Fnetahtml%2FPTO%2Fsearch-adv.htm&r=1&f=G&l=50&d=PTXT&p=1&p=1&S1=7,524,572&OS=7,524,572&RS=7,524,572

Venkataraman, S; Sridhar, K.R; Finn, J.E; Mitlitsky, F; Gottmann, M. (2009) U.S. Patent No. 7,575,822 Washington, DC: U.S. Patent and Trademark office; retrieved from: http://patft.uspto.gov/netacgi/nph-Parser?Sect1=PTO2&Sect2=HITOFF&u=%2Fnetahtml%2FPTO%2Fsearch-adv.htm&r=2&f=G&l=50&d=PTXT&p=1&p=1&S1=7575822&OS=7575822&RS=7575822

VIELSTICH, W, GASTEIGER, H, & LAMM, A. (2004). Handbook of fuel cells - fundamentals, technology,. West Sussex, England: John Wiley & Sons.
Water energy let the power flow!. (2008). Retrieved from http://www.top-alternative-energy-sources.com/water-energy.html

Wind energy basics. (2009). Retrieved from http://www.gepower.com/businesses/ge_wind_energy/en/downloads/wind_energy_basics.pdf

Wiser, R., & Bolinger, M. U.S. Department of Energy, Energy Efficiency & Renewable Energy. (2010).2009 wind technologies market report (GO-102010-3107). Retrieved from http://www1.eere.energy.gov/windandhydro/pdfs/2009_wind_technologies_market_report.pdf

Zakaria, F. (2010, April 23). This is brand new. Retrieved from http://www.newsweek.com/2010/04/22/this-is-brand-new.html