

The Science and Economics of the Bloom Box: Their Use as a Source of Energy in California

MMX

ECON 26800: Energy and Energy Policy

Grayling Bassett
Archibald England
Frank Li
John Weinberger
Andrew Wong

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Introduction

Solid Oxide Fuel Cells (SOFCs hereafter) can provide a wide range of benefits to users for the purpose of electricity generation. In the research we will carry out, we aim to address the question of whether both federal and state policies and the economics specific to SOFCs make them economically viable. We will focus on a particular commercial application of SOFCs, namely the BloomBox. In order to restrain the extent of our analysis, we will also not consider the use of BloomBoxes as a combined heat and power (CHP) unit, since, while this is technically possible, it is far from a common practice, especially in a state such as California, where heating is not a primary concern or one of the primary consumers of energy .

The electricity grid that supplies retail customers in the California, as well as the wider United States, is becoming increasingly burdened with the greater demands placed on it through increased energy consumption as well as the aging of the infrastructure currently in place. In this paper, we will consider the feasibility BloomBoxes, and their potential in helping California meet its energy demands. SOFCs, first developed in NASA's Apollo program, have three qualities that make them attractive as a source of energy in the future:

1. They operate independently of the transmission grid, instead being installed in the homes or offices they are electrifying, so are immune from the inefficiencies inherent in distributing electricity over large distances;
2. The waste heat from the generation process can be used either to heat water or for space heating, increasing the overall efficiency of the units;
3. Since the energy is made electrochemically the fuel cells are far more efficient at generating energy than any source that relies on the burning of fuel.

Despite the benefits of using SOFCs as a source of energy, there are also costs associated with them, including the high cost of initial installation and the problems of manufacturing fuel for the cells, that need to be considered before reaching a conclusion as to whether SOFCs are a viable source of energy that can form a significant portion of the California's energy mix.

At present, fuel cells are already competing with existing technologies in three different, broad markets (stationary power, automotive, and portable and equipment markets), and within each group there are a wide range of applications. This paper, however, will concentrate on BloomBoxes and their use as a source for generating power in the state of California (discounting combined heat and power systems since heating systems are of relatively little importance to overall energy consumption in California).

In 2007, California produced 69.5% of the electricity it uses; the rest is imported from the Pacific Northwest (8.2%) and the U.S. desert southwest (22.3%). Natural gas is the main source for electricity at 45.2% of the total system power. In 2005, Californians spent \$31 billion for their electricity (The California Energy Commission, 2010).

The Science of a Fuel Cell

In order to understand the role that SOFCs may play in the future, it is first essential to understand the science behind the operation of a SOFC in terms of the technology's potential and limitations. In principle, the operation of a fuel cell can be explained as an electrochemical reaction. The basic components of a fuel cell are the anode, cathode, electrolyte, and a wire. A simple illustration is shown in figure 1. In introductory Chemistry courses, a common phrase is "LEO says GIR." This phrase is the key to understanding the chemical reactions that occur in a general fuel cell. The phrase stands for, "losing electrons is oxidation, and gaining electrons is reduction." Hence, in a reaction in which an element loses electrons, the element is said to be oxidized, or an element gaining electrons is reduced. In simplest terms, the anode is the site at which oxidation takes place in a fuel cell. Conversely, the cathode is the site at which reduction takes place. Specifically, the reduction reaction that occurs at the cathode in an SOFC can be written as: $O_2 + 4e^- \rightleftharpoons 2O^{2-}$. The electrolyte is a substance that allows ions such as O^{2-} to migrate between the cathode and anode due to vacancies in the lattice of the ceramic at the atomic level (Ref 1). In a SOFC, the electrolyte is a non-conducting ceramic material that performs well when heated to 750 to 1000^oC(Ref 1). At the anode, the oxidation reactions that occur are: $H_2 + O^{2-} \rightleftharpoons H_2O + 2e^-$ as well as $CO + O^{2-} \rightleftharpoons CO_2 + 2e^-$. Finally, there is a build up of electrons at the anode due to oxidation and a shortage of electrons for further reduction at the cathode. Hence, we can link the anode to the cathode via a wire as shown in figure 1. Electrons will flow through the wire due to the spontaneous oxidation and reduction reactions at the anode and cathode respectively. Electrons are said to be traveling down a potential gradient. This is similar to a ball rolling down a hill. Although a SOFC can run on a variety of hydrocarbon fuels including methane, the hydrocarbon fuels are catalytically reformed so that the gases flowing into a SOFC are CO, H₂, and O₂. The overall reaction in the SOFC is: $H_2 + CO + O_2 \rightleftharpoons H_2O + CO_2 + \text{energy}$. Here, energy takes the form of a potential that drives the flow of electrons as well as heat that warms the exhaust as well as the fuel cell itself. Within a SOFC, many individual fuel cells are connected together via a conducting ceramic material called an interconnect (Ormerod, 2003).

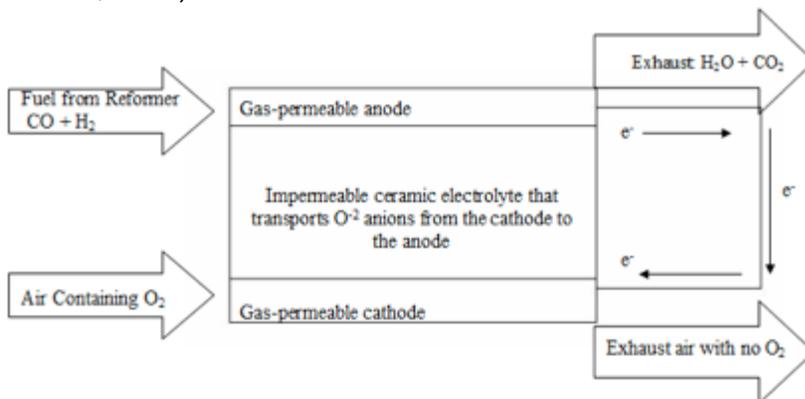


Fig 1. A basic design for a solid oxide fuel cell

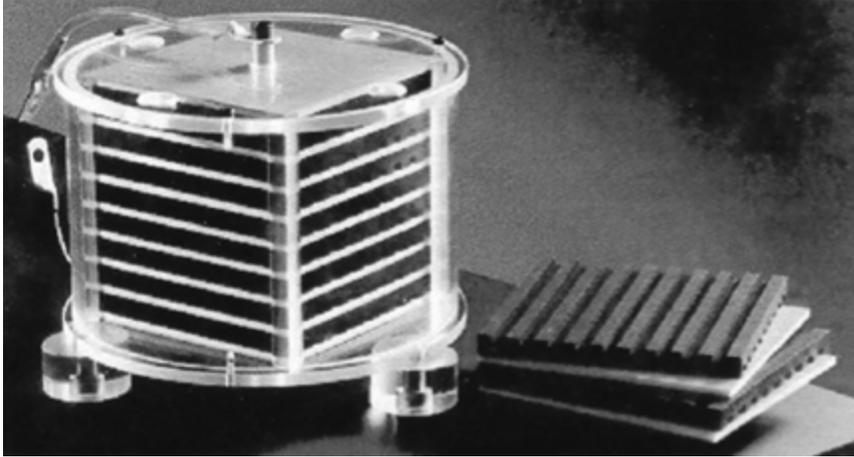


Fig. 2 A prototype planar solid oxide fuel cell stack (Ormerod, 2003)

Technical Advantages of Solid Oxide Fuel Cells

SOFCS present several technical advantages over conventional power plants. These advantages include lower emissions of sulfur oxides, nitrogen oxides, and CO₂ per watt. Potentially, SOFCs are reliable with very little maintenance, and there is potential for applications of SOFCs in applications where power must be uninterrupted such as sensitive electronics or life-supporting equipment (Ormerod, 2003). Additionally, with the advance of carbon capture technology, it could become practical to capture the CO₂ leaving a SOFC. In addition, SOFCs can theoretically reach 80% energy efficiency when the exhaust is run through gas turbines, and they can quietly generate electricity at the site where electricity is required, which avoids inefficiencies and expenses associated with transmitting power from a central power plant to a consumer. This is especially valuable in remote locations and locations that suffer from inadequate electrical generating capacity. Furthermore, SOFCs can operate on a variety of hydrocarbon fuels such as natural gas, which is already distributed throughout many developed countries, and biogas, which is a potential renewable hydrocarbon fuel. In many cases, the waste heat of the exhaust can be used for heating purposes instead of running a turbine to produce more electricity. Thus, SOFCs could be the basis for combined heat and power systems for modern buildings. Furthermore, electricity production can scale to applications where only a few watts are required to megawatts. Water use within a fuel cell is estimated to be 1% to 2% of the water use of a household. Furthermore, the high power density of SOFCs combined with the potential for low emissions has made SOFCs a subject of interest for generating electricity in vehicles potentially to drive the car or to only operate electronics (Ormerod, 2003).

Obstacles and Current Research

Nevertheless, although SOFCs have existed for over the last 160 years, SOFC research stalled until the 1960's because the high temperature of fuel cell as well as the harsh reducing environment created by the gas used as fuel has lead to serious issues in terms of finding suitable materials to construct an efficient fuel cell (Ormerod, 2003). Electrolytes, anodes, cathodes, and interconnects must be able to tolerate harsh conditions. Furthermore,

these ceramic fuel cells are prone to damage during start up and shutdown of the system because ceramics undergo thermal expansion, but they are relatively poor conductors of heat. Consequently, during a warm up or cool down the brittle ceramics will not have uniform expansion and contraction, which causes cracking of the ceramics and failure of the cell. Therefore, current SOFCs are unsuitable for intermittent production of electricity. This limitation has hindered the use of SOFCs in transport applications, which often means rapid cooling and heating of the brittle ceramics. Furthermore, it prevents solid oxide fuel cells from increasing output to follow load demands from a household throughout the day. A household running a SOFC must run either independently from the grid, in parallel with the grid, or it must be run in some combination. A system independent from the grid must use an expensive battery system or limit energy consumed (McClelland and Torro, 2002). A system running in parallel with the grid will either draw power from the grid or put electricity on the grid depending on household electricity use while a combination system will cut itself off from the grid in the event of a power outage. Each option requires expensive electronics (McClelland and Torro, 2002). In terms of estimated costs, assuming maintenance once per year and an operating life of 10 years, the cost of labor, piping assembly, materials, electronics, insulation, natural gas, reformer, and heat exchanger could bring a SOFC system as high as 30 cents per watt of capacity according to some existing designs (DOE NTEL, 2002). Furthermore, because of the relatively small size of 2-5 kilowatt systems companies are unlikely to achieve economies of scale without producing devices in mass quantities (McClelland and Torro, 2002). However, despite technical limitations mentioned in this section, SOFC systems have been reported that last on the scale of years in lab settings (Halinen, Saarinen, Noponen, Vinke, Kiviaho, 2010).

Another limitation of an SOFC system is that energy is lost when the DC current produced by the SOFC must be converted to the 60 Hz AC current required by most appliances. Additionally, thick electrolytes ceramic cause resistance to ion transport. Since the 1960's, research into SOFCs has focused on planar and tubular designs as well as new electrolyte materials that would enable greater efficiency, durability, and lower operating temperatures. In addition, research has also focused on internally reforming hydrocarbon fuels inside the SOFC instead of within an external reformer. This would make SOFCs more economical in that they would simplify the system. However, internal reforming means exposing the anode to sulfur impurities and solid carbon deposition, which poison the anode's ability to function.

Zirconium oxide doped with ytterbium oxide has been found to be an effective electrolyte material because conducts O^{2-} ions and can tolerate an oxidizing and reducing atmosphere (Ref 1). While the costs of pure ytterbium oxide are prohibitively expensive, zirconium oxide is relatively cheap, abundant, strong, electrically insulating, and easy to fabricate (Ormerod, 2003). Other oxides such as scandium oxide and calcium oxide have been used as dopants to zirconium oxide, but ytterbium oxide is generally considered superior for reasons of cost, availability, and stability (Ormerod, 2003). While the operating temperature of a fuel cell is dictated by the electrolyte thickness and ionic conductivity, operating the solid oxide fuel cell below 700^oC would enable cheaper materials to be used in the fuel cell to produce power at high efficiencies (Ormerod, 2003). Hence research on this front has investigated a variety of electrolyte materials as well as designs for thinner electrolytes, which must be supported by

other structures such as the anode or cathode. Currently, consistent thicknesses on the order of 10 micrometers have been obtained (Ormerod, 2003).

Other electrolytes that have shown promise include gadolinia-doped ceria and lanthanum gallate. Unfortunately, gadolinia doped ceria forms Ce^{+3} at high temperatures, which conducts electrons and prevents them from traveling through the interconnect. At temperatures below $500^{\circ}C$, the electrolyte has a sufficient ionic conductivity, but current cathode materials are not active enough to turn O_2 into O^{2-} at a fast rate. Lanthanum gallate does not possess these problems, but its chemical structure changes with temperature, which makes the ceramic electrolyte dramatically more brittle.

In terms of anode composition, the metal used for an anode must resist oxidation under operating conditions, which limits the potential metals to cobalt, nickel, and precious metals. As a result, nickel is a popular anode choice because it is the cheapest, and it is used to make a porous anode by mixing its dust with electrolyte to form a mixture to join to the electrolyte, but this process is complicated by the thermal expansion mismatch between the electrolyte and the nickel (Ormerod, 2003). Research has experimented with adding a third material to this mixture or replacing the anode with an electrically conducting oxide in an effort to improve internal reforming, reduce carbon deposition, and reduce poisoning of the fuel cell with sulfur, which is present in hydrocarbon fuels in trace amounts (Ormerod, 2003).

Additionally, the cathode must also be robust enough to tolerate harsh chemical conditions while being porous and electrically conductive, which limits the choices of material to rare metals or conducting oxides with thermal expansion coefficients close to the electrolyte ceramic. Zirconium oxide SOFCs generally use $LaMnO_3$ doped with strontium. However, temperatures over $1300^{\circ}C$ cause manganese to diffuse into the electrolyte, which impairs fuel cell operation (Ormerod, 2003).

The interconnect must be able to tolerate reducing and oxidizing atmospheres while conducting electricity and preventing the mixing of gases at the anode and cathode. A canonical choice of material for this role is $LaCrO_3$. Although this material conducts 1000 times better in air than in a hydrogen atmosphere, the conductivity of $LaCrO_3$ does not limit performance in current designs (Ormerod, 2003). However, at lower temperatures, it would be feasible to use cheaper materials such as stainless steel composites.

Summary of Technology Status

Overall, much research is required for SOFCs to realize their potential as an efficient and widely desirable means of producing electricity. However, SOFCs have already been shown to be beneficial and attractive for a range of applications. This technology has also been shown to be feasible in a lab setting. Although there is tremendous room for improvement in terms of cost, durability, and efficiency, this technology is ready to produce electricity outside of a lab setting.

Commercial Applications of Solid Oxide Fuel Cells

In the last few years of the origination of methane fuel cells, or solid oxide fuel cells (SOFC), we have seen much growth in the industrial development of this technology. The technology's mobility and minimal maintenance requirements, coupled with relatively low costs, lends itself to numerous industrial utilizations. Thus, there have been many applications of SOFC technology coming to fruition in competitive markets for electricity generation.

Delphi Automotive SOFC APU

In a joint venture with BMW, Delphi Automotive has been developing solid oxide fuel cells for commercial vehicles since 1998. The venture has provided major leaps, particularly in the area of stationary power management. The venture has allowed to produce onto the market a Solid Oxide Fuel Cell (SOFC) Auxiliary Power Unit (APU), producing 5kW of electricity via electrochemical generation. As the fuel converts electricity without combustion, the Delphi SOFC APU operates at higher efficiency levels than previous traditional internal combustion engines, while further eliminating pollutants and noise (Delphi, 2010)

The SOFC APU application of this product has proven to be particularly useful in the transportation industry where this technology can provide an auxiliary power supply, allowing the truck operator access to cab accessories such as “cab lights, refrigerators, microwave ovens, and audio systems” without having to turn on the primary engine or leave it idling. Delphi estimates that the SOFC APU could “save up to 85% of the fuel now required for the operation of the main diesel engine during idling” (Delphi Website, 2010). As seen in the picture (Delphi Website, 2010) below, the Delphi SOFC APU is quite small and is not space intensive.



The partnership between Delphi and BMW has allowed BMW to also implement the technology in their sedans, complimenting the main combustion engine, while reducing variable costs.

Bloom Energy

The most prominent modern application of the solid oxide fuel cells is the “Bloom Box” whose

history stems from Dr. K. R. Sridhar's research group for the NASA Mars exploration program. The group was looking to develop a sustainable, yet efficient, energy source at the Space Technologies Laboratory at the University of Arizona, but later moved on to form the current company, Bloom Energy in 2001-2002, after securing funding from a few venture capital firms (Bloom Energy Website, 2010).

The latest Bloom Box model, the Bloom Energy ES-5000 which can intake natural gas, hydrogen, or even garbage dump gas costs \$700,000-800,000 (Bloomberg, 2010). It is capable of generating 100kW, enough electricity for approximately 100 homes. Since its entrance into the market in July 2008, it has been bought several Fortune 500 firms including Google, Staples, Walmart, FedEx, Coca-Cola, and Bank of America (Bloom Energy Website, 2010). Its proven reliability and economic efficiency has been shown in eBay's decision to use this SOFC fuel source in generating 15% of the electricity consumed in its main San Jose, California headquarters (Christian Science Monitor, 2010). Such widespread use of this product is no mistake as it is highly economical, generating electricity at 8 to 10 cents a kilowatt hour, albeit with subsidies from the state of California, much lower than the usual commercial cost of electricity at 14 cents/kilowatt hour (New York Times, 2010).

This seemingly miraculous technology does come with a few disadvantages and hurdles however. Besides the high upfront capital costs, solid oxide fuel cells also relies on extremely high operating temperatures, around 800-1000 degrees Celsius. As a result, Bloom Boxes may be vulnerable to breaking down if not managed and serviced properly. Furthermore, this technology requires a slow startup as it needs to heat up to the high operating temperature before being able to fully run (Scientific American, 2010). Most of the dangers of such a high operating temperature are harnessed, but it still causes some hindrances when it comes to efficient operation.

Ceres Power

While the disadvantages of the Bloom Box is the high temperature, there have been competitors such as Ceres Power looking to capitalize on this weakness and develop an improved solid oxide fuel cell with lower operating temperatures. By replacing the original anode material, yttria stabilized zirconia (YSZ,) with cerium gadolinium oxide (CGO), Ceres has been able to reduce the operating temperature from 800-1000 degrees Celsius to 500-600 degrees Celsius. This significant reduction in temperature allows the electrochemical layers to be thinner, and improving performance, while reducing material costs. Additional advantages to Ceres Power's development also include thermal shock resistance, fast start-up times, and more mobility (Ceres Power, 2010).

A common thread that we have seen in the application of solid oxide fuel cells technology brought onto the market is that it is competing in highly competitive markets. The versatility of this product to be used from commercial and residential electricity generation to automobile auxiliary power proves the extent to which such a powerful technology can be applied. SOFC technology's impact in the future is imminent when costs eventually lower from further improvements in research and development, allowing it to beat alternatives with higher costs.

The Natural Gas Market

The primary fuel for the solid oxide fuel cell is methane, which is the main constituent of natural gas. According to the Bloom Energy website, the ES-5000 Energy Server consumes 0.661 MMBtu/hr of natural gas to produce 100 kW of electricity. A cubic foot of natural gas produces approximately 1000 Btu's, so the ES-5000 Energy Server consumes natural gas at the rate of approximately 661 cu. ft. per hour. To put that number in some perspective, according to 2008 figures from the American Gas Association, the average household in the U.S. consumes approximately 9 cu. ft. of natural gas per hour for heating and cooking. The Bloom ES-5000 Energy Server consumes approximately as much natural gas to produce 100 kW of electricity as 73 homes consume on average for heating and cooking.

Because natural gas is the primary fuel for solid oxide fuel cells, the commercial viability of the technology depends in part on the price of natural gas. Price projections for any market priced commodity are speculative by nature. For natural gas, future prices are complicated by price variations between geographic regions and by retail prices which vary depending on the size of the customer. Wholesale electricity generators pay less per cubic foot than households.

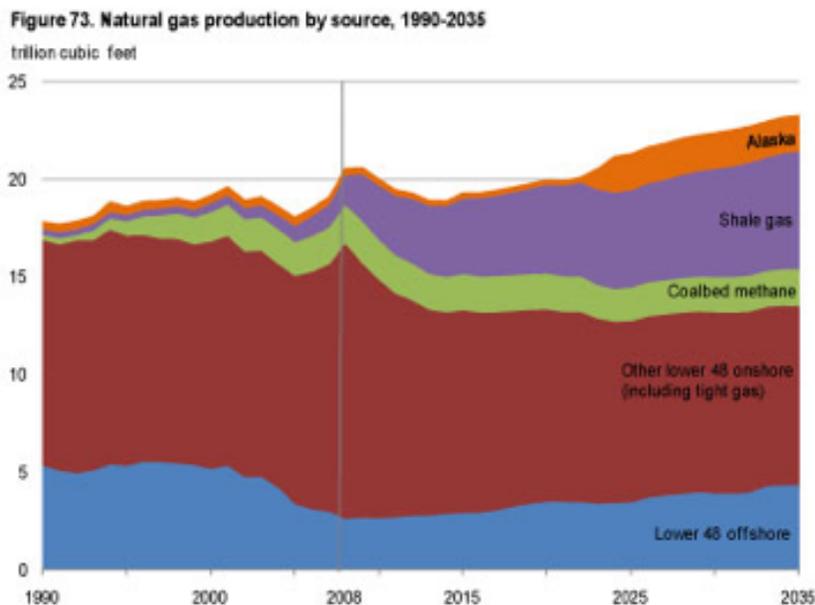
Demand for natural gas as a fuel for electric power generation has grown slowly but steadily for the past twenty years. It is an attractive fuel for electric power because it is clean burning and efficient, and because ample supplies of natural gas have been available from domestic resources and from Canada. In fact, the vast majority of new electricity generation capacity built in the United States in the past decade has been natural gas-fired.

The most dramatic long-term factor in the U.S. natural gas market is the discovery of vast domestic reserves of natural gas from unconventional sources including deep-well gas, coalbed methane, tight sands gas, and most importantly, shale gas. The most significant trend in U.S. natural gas production is the rapid rise in production from shale formations. In large measure this is attributable to advances in the use of horizontal drilling and well stimulation technologies and refinement. Hydraulic fracturing – the high pressure injection of water, sand and chemical lubricants into underground shale formations - is the most significant of these technologies. A few years ago, most analysts foresaw a growing U.S. reliance on imported sources of natural gas, and significant investments were being made in regasification facilities for imports of liquefied natural gas (LNG), according to the Energy Information Administration (EIA).

How shale gas will affect future prices is uncertain. Shale gas is more expensive to produce than natural gas from traditional underground reservoirs. Furthermore, there may be technical or environmental factors that might dampen shale gas development, but analysts agree that the potential supply is enormous.

The boom in natural gas from shale formations began in the mid-1990s. At that time, shale deposited natural gas provided about 1 percent of the Lower 48 production. By 2008, however, the shale production rose to occupy almost 10 percent of production from the Lower 48. According to the Natural Gas Supply Association, production from shale could double in the

next 10 years and provide one-quarter of the nation's natural gas supply. The EIA's Annual Energy Outlook 2010 predicts that total domestic natural gas production will grow from 20.6 trillion cubic feet in 2008 to 23.3 trillion cubic feet in 2035. With technology improvements and rising natural gas prices, natural gas production from shale formations is predicted to grow to 6 trillion cubic feet in 2035, more than offsetting declines in other production. In 2035, shale gas is estimated to provide 24 percent of the natural gas consumed in the United States, up from just 6 percent in 2008.

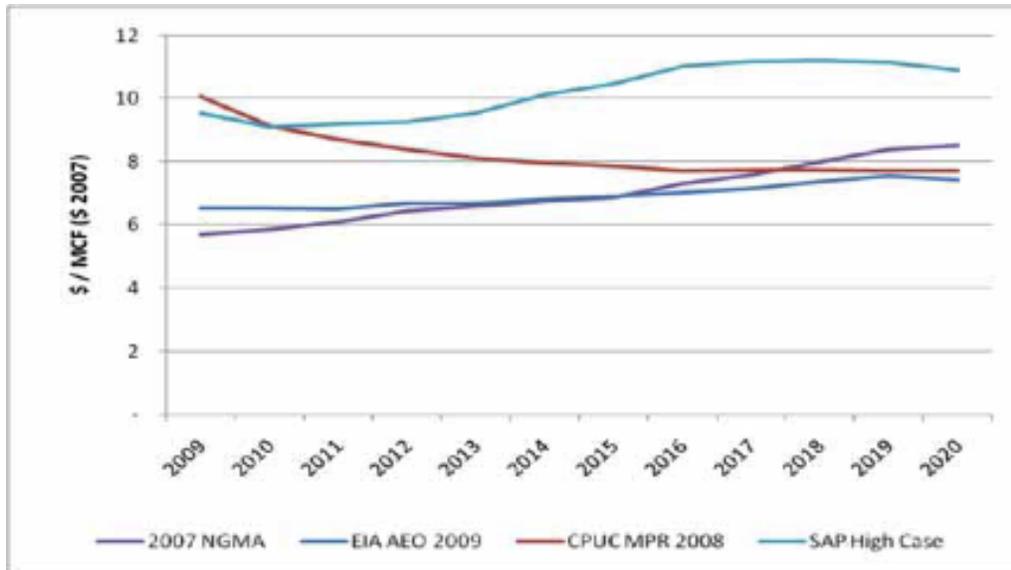


Natural Gas Consumption in California

According to the California Energy Commission, natural gas demand for the electric power sector in California is expected to increase by 2.4 percent over the next decade, while overall gas demand in all sectors is forecast to increase slightly higher than 1 percent annually. Some contributing factors to this slower growth in overall demand are: (1) increased use of renewable energy; (2) slower growth rate in electric generating capacity; (3) more fuel-efficient natural gas power plants; (4) flat growth in the industrial sector; (5) improved efficiency requirements for buildings and appliances through standards; and (6) new demand-side management programs. This slow growth in demand bodes well for natural gas prices in California.

Natural Gas Price Forecasts

Source: California Energy Commission



The above figure compares four Henry Hub natural gas spot price forecasts through the year 2020: (1) California Energy Commission's *2007 Final Natural Gas Market Assessment* (2007 NGMA) prepared in support of the *2007 Integrated Energy Policy Report, Energy Information Administration's Annual Energy*; (2) *Outlook 2009 (EIA AEO 2009)*; (3) Energy Commission *Scenario Analysis Project Case 2 (SAP High Case)*; and (4) California Public Utilities Commission (CPUC) *Market Price Referent (CPUC MPR 2008)*.

California Energy Commission: 2007 Natural Gas Market Assessment, Final Staff Report

This model predicts an upward trend in natural gas prices to about \$6.50 per million cubic feet in 2020. The 2007 NGMA natural gas price forecast was produced using the Market Point, Inc., World Gas Trade Model (WGTM)/ North American Regional Gas (NARG) component, produced as part of a natural gas market assessment, and in support of the Energy Commission *2007 IEPR*. The WGTM is a generalized, equilibrium model that produces market-clearing natural gas wholesale prices, quantities, natural gas production, and pipeline flows at a market equilibrium of supply and demand. The model simulates the physical structure of the market, accounting for expected market changes.

Energy Information Administration Annual Energy Outlook 2009 Forecast

This model predicts a slight upward trend in natural gas prices leading to a price of about \$7.50 per million cubic feet in 2020. The EIA AEO 2009 forecast was produced using the National Energy Modeling System (NEMS). This annual forecast is widely used by analysts, planners, and decision makers inside and outside government for study, analysis, planning, and investment decisions. NEMS contains separate modules for regional fuel markets and consumer sectors (i.e. industrial, commercial and residential), as well as macroeconomic and international modules. The model balances supply and demand for each of the fuel markets, while accounting for competition between different fuels.

California Public Utilities Commission, Market Price Referent 2008

This model, based on NYMEX natural gas forward contract prices predicts a declining trend in natural gas prices to just under \$8 per million cubic feet in 2020. In accordance with California's Renewables Portfolio Standards Program, the CPUC develops a natural gas price forecast (CPUC MPR 2008) to establish an avoided electricity cost benchmark, the Market Price Referent (MPR) for non-renewable energy. The MPR then serves as a benchmark to evaluate the reasonableness of the prices paid by investor-owned utilities for renewable energy.

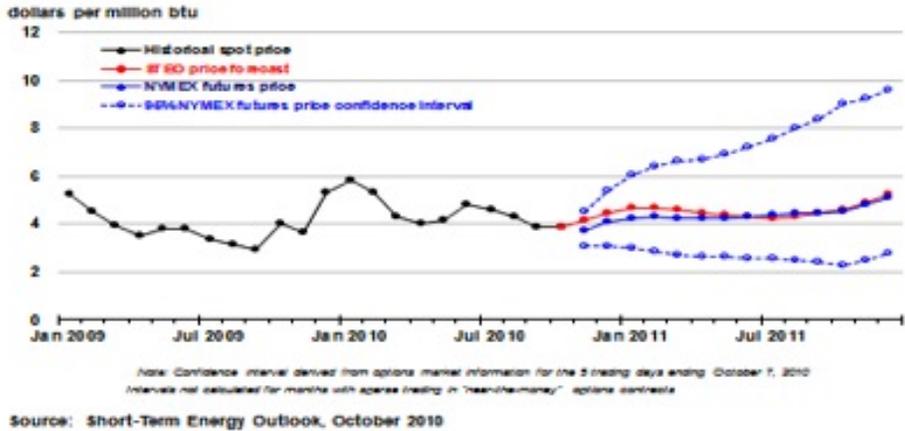
California Energy Commission 2007 Scenario Analysis Project—Case 2—High Sustained Natural Gas and Coal Prices

This is the high price scenario assuming a decline in domestic production over the next ten years. It puts natural gas prices at close to \$11 per million cubic feet in 2020. The Scenario Analysis Project, prepared in support of the California Energy Commission *2007 IEPR*, was designed to provide a greater understanding of the implications of various levels of market penetration of "preferred resources," such as energy efficiency measures and renewable electricity generation, in both California and the Western states. In support of developing one scenario, SAP Case 2, the High Sustained Natural Gas and Coal Prices, Global Energy Decisions' Gas Pipeline Competition Model (GPCM), which allows users flexibility in analytical structure, was used to forecast gas prices that potentially could result from a prolonged scarcity of domestic natural gas supply. Major GPCM assumptions for this scenario included:

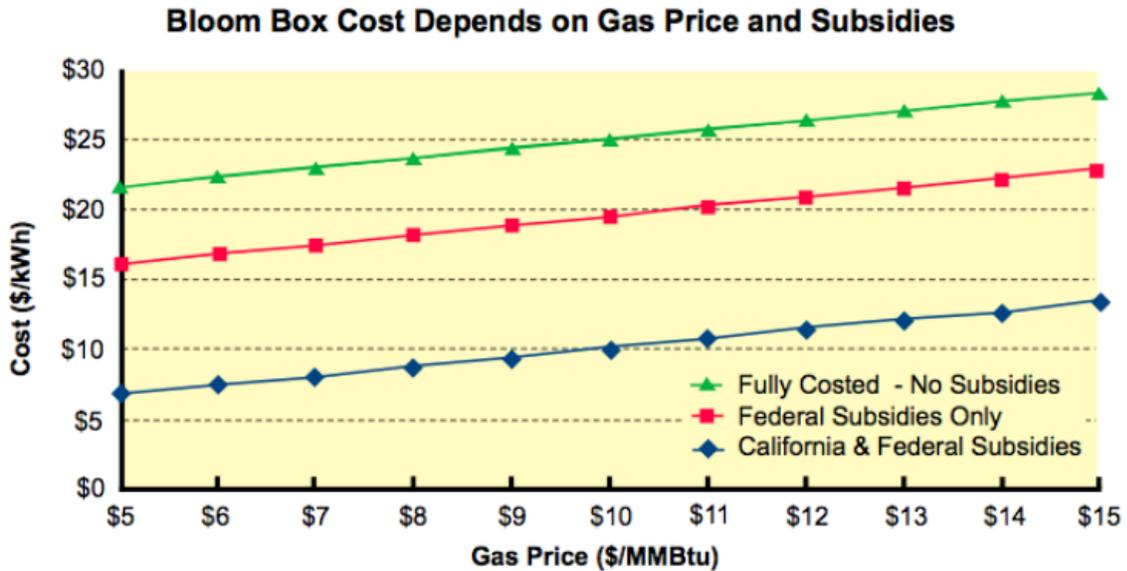
- Domestic natural gas production declines between 12 to 32 percent over the forecast period.
- Neither the Alaska North Slope nor MacKenzie Gas Project pipelines are constructed during the forecast period.
- LNG imports increase, supplanting the declining domestic supply.
- High oil prices and a closer correlation between oil and natural gas prices would result if climate change regulatory policies accelerate the use of natural gas for electric generation.

The current December 2010 New York Mercantile Exchange (NYMEX) price for natural gas is \$4.03 per million cubic feet. January 2020 natural gas futures contracts are currently trading on the NYMEX at a price of \$6.98. The mean 2020 projection of the NYMEX price and the four models described above is approximately \$8 per million cubic feet. If we discard the California Energy Commission high price scenario model, the mean forecast price for 2020 is approximately \$7.25.

The figure below illustrates short-term forecasts through 2012 with a NYMEX futures price 95% confidence interval roughly between \$3 and \$10.



The following graph shows the impact of gas price on the over cost (\$/kWh) of energy produced by the BloomBox, as well as the impact of federal and California state subsidies on the price.



Benefit-Cost Analysis

Assumptions in our Calculations

Discount rate

We chose a discount rate of 7%. This figure is based on using a methodology based on rate of return on private investment. The Office of Management and Budget (U.S. government agency) states:

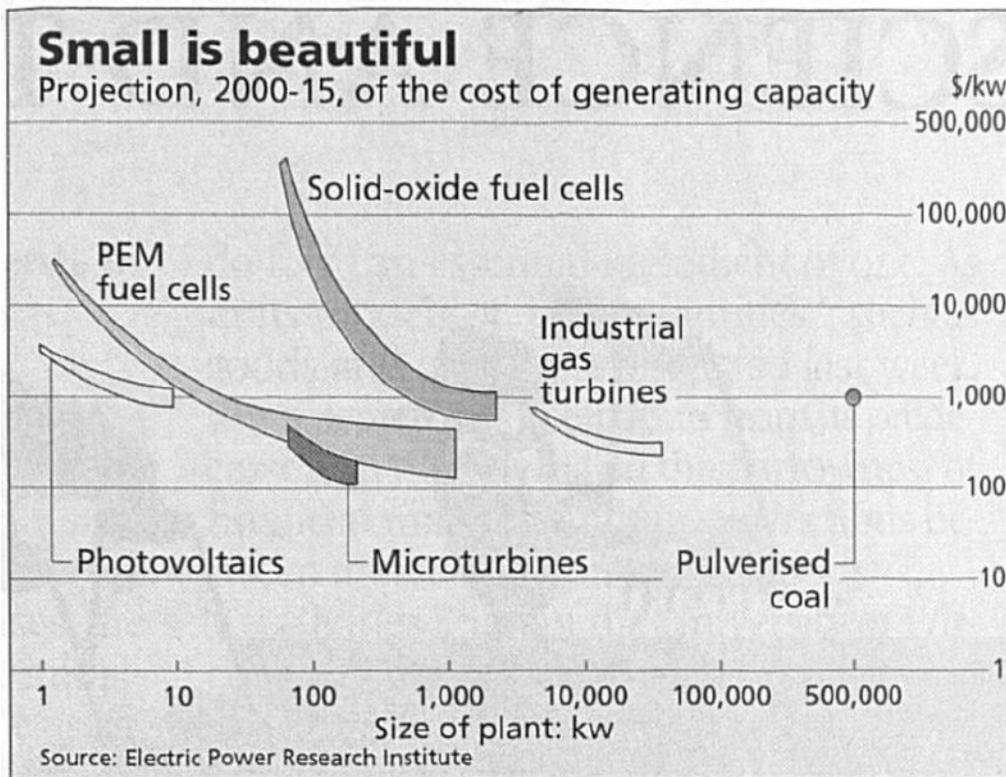
“Base-Case Analysis. Constant-dollar benefit-cost analyses of proposed investments and regulations should report net present value and other outcomes determined using a real discount rate of 7 percent. This rate approximates the marginal pretax rate of return on an average investment in the private sector in recent years. Significant changes in this rate will be reflected in future updates of this Circular” (Office of Management and Budget, 2009).

Time-frame

The time-frame for the analysis is based on the predicted lifespan of BloomBox of 10 years, and we will calculate levelized costs across this 10 year time-frame.

Private Benefits and Costs

BloomBox Technical Specifications and Price Sensitivities



The above graph, shows the projected cost of generating capacity of solid-oxide fuel cells

(of which BloomBoxes are one type) relative to other energy sources. What is clear from the diagram is the following:

- The obvious problem with fuel cells is that they require the end-user to pay a large fixed cost in order for the unit to be installed, despite the subsidies they have
- Fuel cells are clearly more economically feasible for larger consumers of energy (i.e. office buildings rather than typical family households)
- Surprisingly, SOFCs can compete with pulverized coal as a cost-effective fuel for generating capacity, given large plant size, although this is dependent on a necessarily low gas price level (Seattle, Washington is an example of high gas price levels preventing SOFC being efficient, according to City of Seattle, 2010)

Looking at the costs of operating a Methane Fueled Solid Oxide Fuel Cell (M-SOFC), the two immediately noted costs are the fuel stock (Natural Gas) and the up-front capital costs of the system. Other costs such as maintenance, financing and insurance can be factored with the capital cost (including and fuel cost into an average cost of the system).

A M-SOFC like the BloomBox consumes 660,000 BTUs of natural gas in an hour to produce 100KW of electricity (Bloom Energy, 2010). For natural gas, there is approximately 1000 BTU's per 1 cubic foot. Natural gas prices are quoted using 1000 cubic feet (KCF), so a device like the BloomBox consumes 0.66 KCF per 100 kiloWatt-hours (KWH) of electricity produced. To find the cost of each individual KWH, the price of natural gas times the consumption of the device, then divided by the output will give the marginal price of that unit of electrical energy. Here, the price of gas times 0.0066 will give the cost of each additional KWH produced. Because the price of natural gas fluctuates daily as producers, retailers, and consumers negotiate prices over different periods, finding an "average" marginal cost of cast will be based on projections of the gas market, and the certainty of those fluctuations. For 2008, an average cost for 1000 cubic feet of natural gas in California was \$8.34, which at that price would yield a price of 5.5 cents per KWH. But this is not the complete picture.

Tallying the price-tag of the system with additional costs such as initial set-up costs, financing, and maintenance, with deductions for direct subsidies and/or tax-rebates will give a system cost (not the cost of operating the system). The system will have some life-time over which it operates, in this case hours of electrical generation. Taking the cost of the system divided by the product of the hourly generation capacity by the total number of hours the system is expected to run will yield a production capacity cost for the the system. By adding the production capacity cost of the system to the marginal cost, an average cost value is found.

In the BloomBox example, the capital cost per unit is advertised at \$800,000 for a 100KW generation capacity. Cost of financing the system is difficult to ascertain, as different organizations will have different funds available to them as to what loans, if any, and what interest they will pay. Maintenance costs are unknown, but can be explored through assumed annual rates. Financing, insurance and scheduled maintenance (and average projected unscheduled maintenance) and other yearly costs discounted and added as upfront costs can

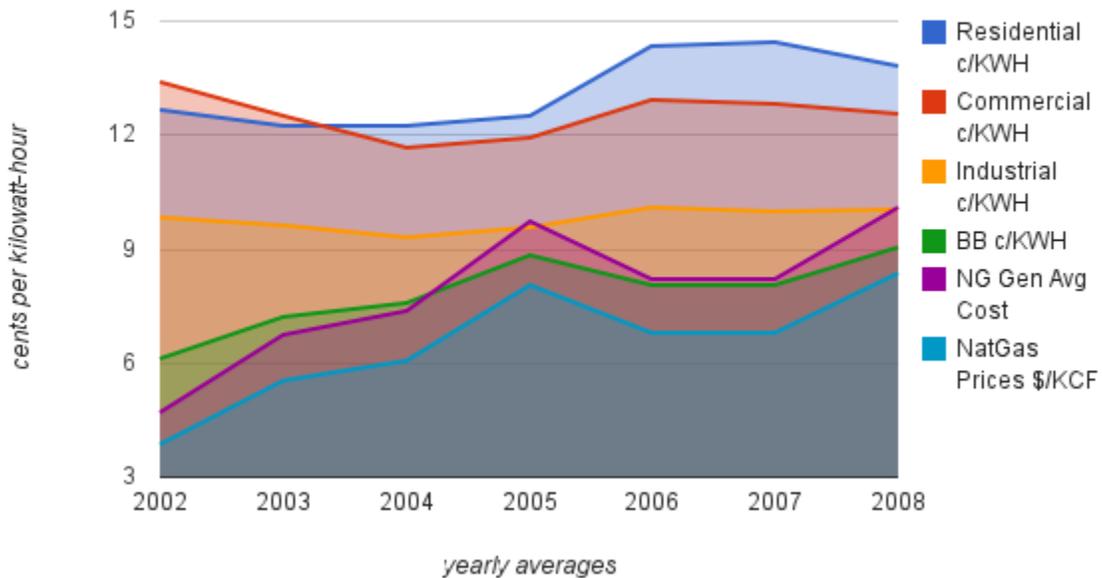
give a present value of the system. Subsidies as tax-breaks, tax-rebates, or direct subsidies can be deducted from the the up front cost of the system (or deducted and discounted for when the purchaser of a such a system is given the subsidy). The Federal Business Energy Investment Tax Credit covers 30% of the cost of a fuel cell system, up to \$1,500 per 0.5 KW of generating capacity (DSIRE, 2010) (or \$3,000,000 per MW), and the state of California has a \$2.50 / Watt of generation capacity incentive for fuel cells that consume natural gas (Center for Sustainable Energy California, 2010) up to 1MW generation capacity, although a system that is fed from renewable fuels receives an incentive of \$4.50 / Watt generation capacity (again, up to 1MW). These additional incentive to Businesses in California maybe the primary reason why many companies in California are purchasing these systems.

To maximize the subsidy for this system, a company may wish to purchase the maximum amount covered by the subsidies, which in California is 1MW of generating capacity. A 1MW BloomBox system has a capital cost of \$8,000,000, a federal subsidy of \$2,400,000, a California subsidy of \$2,500,000. Before maintenance and financing, the cost of a 1MW Bloom system is down to \$3,100,00, generating 87,660,000 KWH of energy (8766 hours/year, 100KW per hour per unit, 10 units in system, over the proposed 10 year life span of the system) (Woody, 2010), bringing the production capacity cost of such a system to around 3.5 cents/KWH, or \$35 per MWH. Without these subsidies, that capacity cost 9.13 cents per kiloWatt hour (\$91 per MWH).

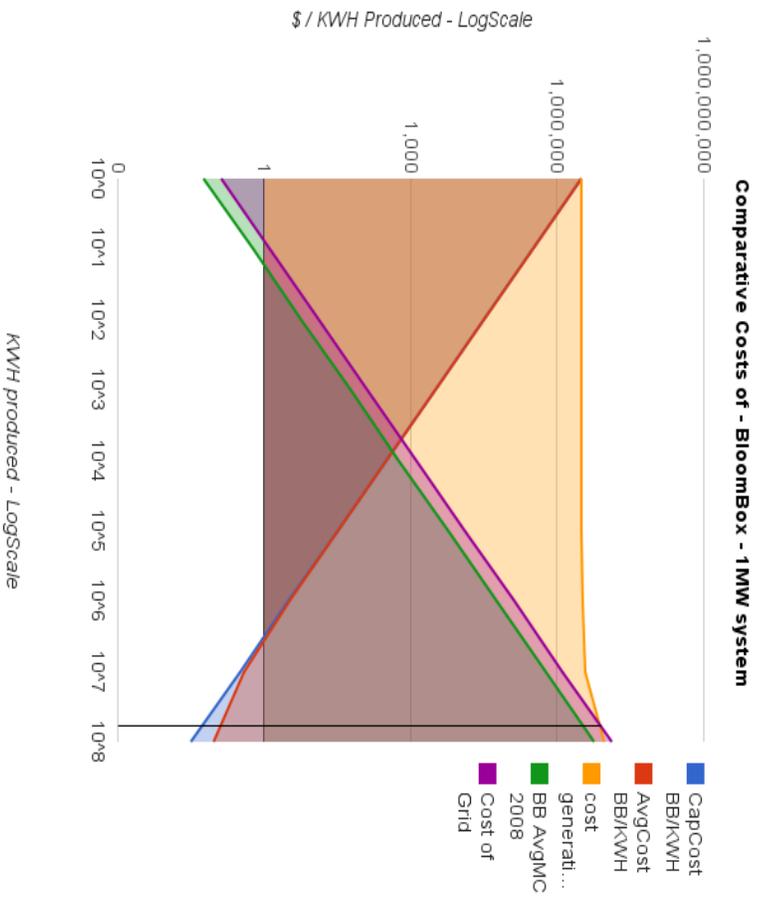
Adding then the Marginal Cost of the Fuel Consumption (5.5 cents/KWH) with the production capacity cost (3.5 cents/ KWH for the purchase of the system, not including maintenance, financing or insurance) does one see the cost of a 1MW system in California at 9 cents/KWH. In comparison with drawing electricity from the electrical grid system, where the average price for commercial users of electirity was 12.54 cents /KWH. The 3.5 cents/ KWH price difference would lead to a savings of \$616,000 in one year. With a discount rate of 7%, 10 years of using the 1MW system at these prices for natural gas (\$8.34/KCF) and the commercial price of electricity (\$12.54), the savings between drawing from the grid and using the BloomBox would pay for the BloomBox system in just over 5 years, with the remaining lifetime of the system returning \$2,300,000.

However, this positive return on the BloomBox is only applicable with the extant price supports and these price levels. If California were to repeal this incentive, the production capacity cost would raise 6.3 cents / KWH, with an average cost of 11.9 cents /KWH, making the pay-back period on a BloomBox 9.1 years, yielding a savings of \$420,000 (before maintenance, financing, and insurance). With no price supports, the BloomBox has a 13 year pay-back period, 3 years longer than the expected system lifetime, at a cost of \$1,400,000 over that of using the same amount of electricity from the grid. If there were a greater difference between the price of natural gas and the commercial price of electricity, or if the BloomBox had technical improvements in its fuel economy or if there were a reduction in its purchase price, then that payback period could be reduced for the system to not be a net expense. For example, at the prices for natural gas and commercial electricity used above, the 1MW BloomBox system would need a purchase price of \$6,160,096 (\$616,010 per BloomBox unit).

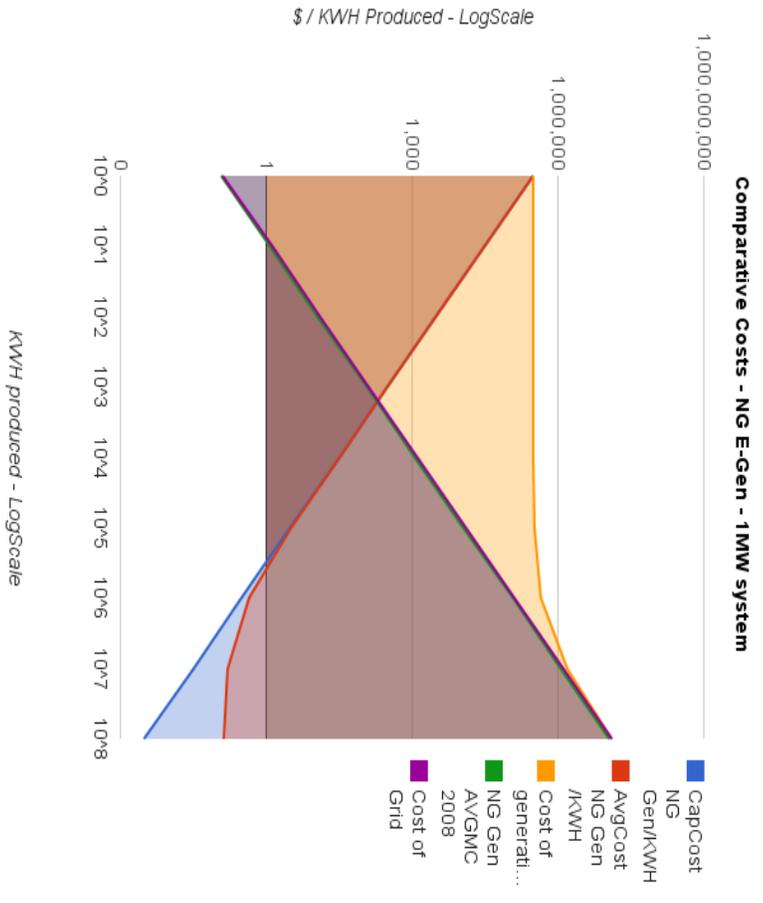
California End-User Price Electricity - Estimates for BloomBox and Natural Gas Electrical Generator



As a comparison, a non-subsidized system of 10 piston-driven reciprocating type 100 KW natural gas fed electric generators, price tag \$30,000 per generator (Norwall PowerSystems, 2010 and Generac Power Systems, 2009) (for \$300,000 purchase price) has a production capacity cost of 0.34 cents /KWH, but consumes fuel at approximately twice the rate of the BloomBox (making the marginal cost of consumption 1.34/100 times the price of natural gas). At the same prices used above for gas and electricity with the M-SOFC, the average cost is 11.5 cents /KWH, but because of the low initial capital cost, this system has a 2.5 year payback period. However, because of the high average cost (mostly due to the 11.1 cents / KWH marginal cost of generation) the system would save \$680,000 over 10 years (discounted at 7%) compared to the purchasing the same amount of power from the grid, prices staying unchanged. For a BloomBox to have a similar savings with no price supports, it's initial price would be \$5,256,750 for the 1 MW system (\$525,675 per unit).



Graph showing the Costs for a 1 MW BloomBox system in terms of dollars per KWH produced.



Graph showing the Costs for a 1MW Natural Gas Generation system in terms of dollars per KWH produced.

Although these analyses have been done using static prices for electricity and natural gas, allowing for variations in price based on projection scenarios compiled by the U.S. Energy Information Administration, the value of these systems can be seen over their projected time of usage. Using national projections from the Annual Energy Outlook 2010 (by the USEIA), there are two scenarios that illustrate the how beliefs in future prices may influence a decision to purchase such a electrical generation system. Electricity prices are projected in terms of a baseline reference estimation, with a range given around that allowing for strong or weak economic growth (US Energy Information Administration, 2010a). Natural gas prices are given around a baseline with the range determined by high or low oil prices (US Energy Information Administration, 2010b). Using the opposite ends of electricity/natural gas prices can be used to find the maximum and minimum projected differences of the system. Projecting prices for California's by using historic price differences with data collected from EIA for the prices of Natural Gas used in electricity generation (being more expensive in California by a factor of 1.43), and the commercial price of electricity (more expensive by a factor of 1.39), the extreme projected scenarios show that using a BloomBox in California can be as much **\$3,150,000** in a strong growth economy with low oil prices, or **\$2,170,000** in a weak growth economy with high oil prices (both figures discounted at 7% over a 10 year period from 2011 to 2020, not including maintenance, financing or insurance costs, in 2009 dollars). Comparatively, a natural gas-fed conventional combustion electrical generator in a high growth, low oil price scenario would cost **\$2,300,000** less than purchasing the same amount of power from the grid at projected commercial rates, and in a low growth, high oil price scenario would be **\$700,000** less than the grid (again, discounted at 7% between 2011 and 2020, not including maintenance, financing and insurance, at 2009 USD). Compared to the 2009 static prices for natural gas and commercial electricity, the current projections favor the use of a BloomBox for power generation over the grid at the 1 megawatt scale in California.

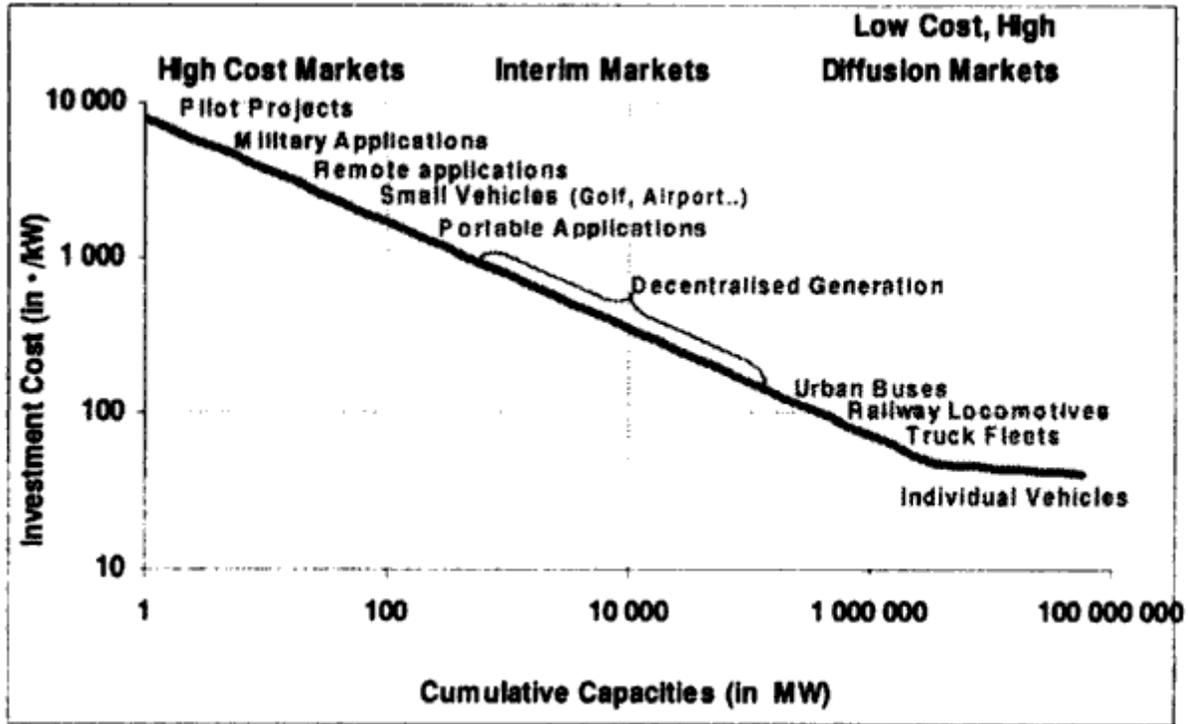
Reliability

Given that BloomBoxes by-pass the grid and are not susceptible to outages caused by adverse weather conditions, they will benefit the user by providing a reliable source of energy. However, given the wide variation in reliability across the state of California, this study will not try to quantify the benefit of increased reliability.

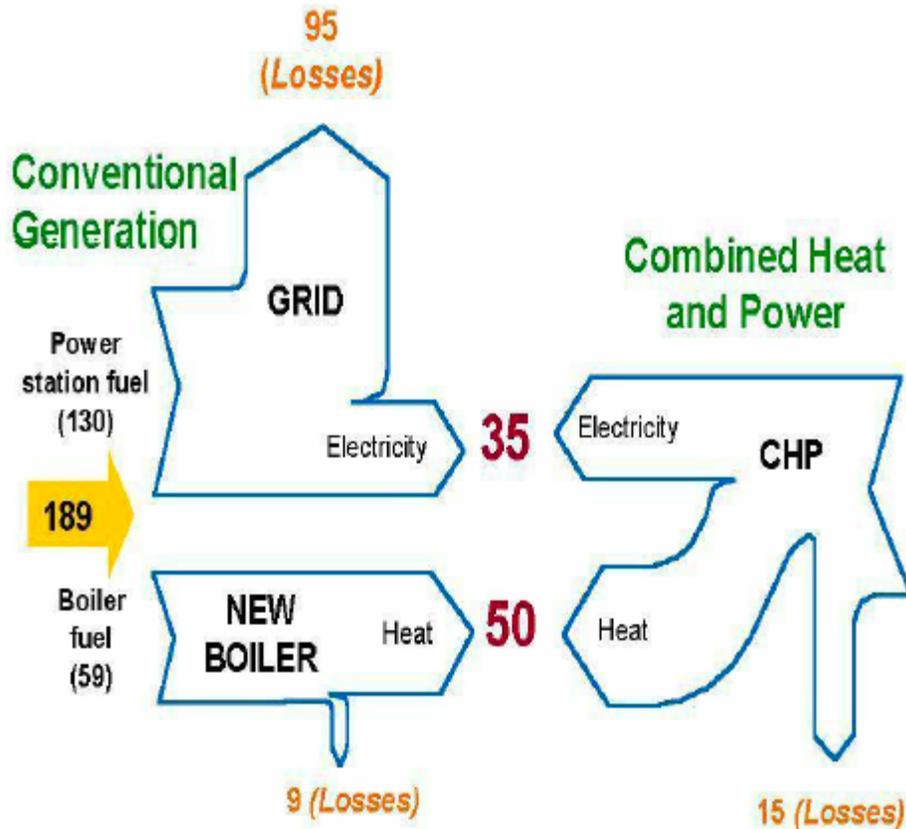
Social Benefits and Costs

Reduced Carbon Dioxide Emissions From Bypassing Power Grid

The graph below shows the scope of decentralized generation as a market for power generation. While it illustrates decentralized generation has a wide range of potential applications, high temperature fuel cells such as SOFC tend to be "less flexible, thereby particularly suiting larger-scale base-load applications" (Avadikyan, Cohendet, & Heraud, 2003: 61).



While the below figure was designed to illustrate the efficiencies of a Combined Heat and Power (CHP) system over a conventional power generation and supply, it is nonetheless abundantly relevant to the use of BloomBoxes in California, since, like CHP system, they bypass the grid. Given that we are only considering the use of SOFC to provide power, and not heat, the benefits we will consider will be somewhat less than the below diagram outlines, but since the vast majority of power use in California is not used to heat, there will still be huge efficiencies in the adoption of SOFC, including BloomBoxes, as a source of power.



If we put a carbon price of \$13.70 per tonne of carbon dioxide emitted, we would be able to quantify the benefits of reduced emissions as a result of the use of BloomBoxes to supply power without the use of the inefficient grid system. This price was chosen since it is the price put on carbon dioxide under the cap-and-trade system proposed by President Obama (Business Green, 2009). I will also use a lower estimate and upper estimate for carbon prices to give a range to the varying degrees of decentralization of energy production that might occur.

As we can see from the diagram, only around 35 of the 130 units (27%) of energy generated at the power plant reaches the end user; since we know California generated 490 MMT (million metric tonnes) of CO₂ emissions for in-state electricity generation in 1990 (California Environmental Protection Agency, 2007), we can thus calculate the emissions stemming from the electricity lost in transmission:

%power lost in transmission x total emissions from power generation x carbon price

$$.73 \times 49,000,000 \times 11 = 393,470,000$$

$$.73 \times 49,000,000 \times 13.7 = 490,049,000$$

$$.73 \times 49,000,000 \times 15 = 536,550,000$$

The following table is based from these calculations. However, since it is unthinkable that California will dispense with the need for a transmission grid in the near future, the table outlines

the varying degrees of benefits based on the varying price of carbon and the percentage of energy bypassing the grid.

Benefits from reduced emissions over one year period based on 1990 emissions figures (since we were not able to find more recent figures pertaining to emissions resulting from power transmission) and carbon prices in the year 2009:

Benefits depending on degree of decentralization over one-year period based on 1990 emissions figures:

Carbon Price (2009\$)	Percentage Power Generation From Non-Grid Reliant Sources										
	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
\$11.00	\$0.00	\$39,347,000.00	\$78,694,000.00	\$118,041,000.00	\$157,388,000.00	\$196,735,000.00	\$236,082,000.00	\$275,429,000.00	\$314,776,000.00	\$354,123,000.00	\$393,470,000.00
\$13.70	\$0.00	\$49,004,900.00	\$98,009,800.00	\$147,014,700.00	\$196,019,600.00	\$245,024,500.00	\$294,029,400.00	\$343,034,300.00	\$392,039,200.00	\$441,044,100.00	\$490,049,000.00
\$15.00	\$0.00	\$53,655,000.00	\$107,310,000.00	\$160,965,000.00	\$214,620,000.00	\$268,275,000.00	\$321,930,000.00	\$375,585,000.00	\$429,240,000.00	\$482,895,000.00	\$536,550,000.00

The above table shows the increasing benefits seen when more energy is supplied via on-site methods. On one extreme, if all energy in California bypasses the grid and is generated at the point it is consumed, and we take the upper estimate carbon price, we would see the benefits of reduced carbon emissions over a one-year period at **\$536,550,000** (in 2009 dollars), which would certainly help California ameliorate its current budgetary predicament.

If 5% less energy than the total amount of energy transmitted by California’s power grid in 1990 was transmitted, than, given the range of carbon prices outlined above, we can calculate the annual average benefits in 2009 dollars using a discount rate of 7%. As the below table shows, if energy transmitted over the grid decreases 5%, then the annual benefits of the reduced emissions of carbon dioxide range from **\$22,651,491** to **\$27,388,274**.

Benefits of reduce emissions if BloomBoxes reduce power sent over grid by 5%:

Carbon Price (2009\$)	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	Net Benefits (2009\$)	Annual Levelized Benefits (2009\$)
\$11.00	\$19,673,500.00	\$21,050,645.00	\$22,524,190.15	\$24,100,883.46	\$25,787,945.30	\$27,593,101.47	\$29,524,618.58	\$31,591,341.88	\$33,802,735.81	\$36,168,927.32	\$271,817,888.97	\$22,651,490.75
\$13.70	\$24,502,450.00	\$26,217,621.50	\$28,052,855.01	\$28,894,440.66	\$29,761,273.87	\$30,654,112.09	\$31,573,735.45	\$32,520,947.52	\$33,496,575.94	\$34,501,473.22	\$300,175,485.26	\$25,014,623.77
\$15.00	\$26,827,500.00	\$28,705,425.00	\$30,714,804.75	\$31,636,248.89	\$32,585,336.36	\$33,562,896.45	\$34,569,783.34	\$35,606,876.84	\$36,675,083.15	\$37,775,335.64	\$328,659,290.43	\$27,388,274.20

Since earlier analyses use the predicted and advertised lifespan of a BloomBox, 10 years, to calculate the benefits of reduced carbon dioxide emissions would likewise seem appropriate to use the 10 year lifespan. Thus, we can calculate, that if enough BloomBoxes were used from 2009 to reduce the amount of power transmitted across the grid by 5% there would be total benefits stemming from reduced carbon dioxide emissions of between **\$271,817,889** to **\$328,659,290** (in 2009\$).

Reduce Carbon Emissions from Power Generation

Distinct from the benefits gained in bypassing the power grid, the adoption of BloomBoxes would mean that less energy would be sourced from greenhouse-gas emitting power plants. However, given the lack of up-to-date information on how California sources its energy, and given that California has policies outlining its intentions to reduce emissions, we will not try to quantify these benefits.

Reduced Availability of Rare Metals

Orthodox fuel cells require rare-earth metals such as platinum or palladium to act as a catalyst to drive the reaction. However, as a result of the secrecy around BloomBoxes, it is currently unclear what rare-earth metals it uses or whether it uses them at all. Therefore, for the purposes of this analysis, we will not attempt to quantify the impact of the increased demand on rare-earth metals.

Conclusions

While the BloomBox is on the edge of technological innovation, there is a lot we do not know about its performance. Most significantly, there have been no BloomBoxes in operation long enough to know if they usually last the 10 years their makers claim they can. Nonetheless, since they are in operation, famously at companies including Google and Ebay, more will soon be known about their actual performance as opposed to any theoretical estimations. As has been written by Avadikyan, Cohendet, and Heraud: “fuel cells may have started to cross the bridge from research and demonstration to the point where they may turn progressively competitive with conventional power generation technologies, once a sufficient level of production will be reached (> 10 GW/year). Stationary fuel cells may encounter a thriving market if developers stick to their promises to deliver reliable systems at competitive prices in the near future” (Avadikyan, Cohendet, & Heraud, 2010: 76).

Given California’s leading role in tackling greenhouse gas emissions, and their target of reducing their emissions to 1990 levels by 2020, and 80% below 1990 levels by 2050, it seems that from a policy standpoint BloomBoxes would be an ideal way for the state to meet its energy needs. As we have seen, if the amount of energy sent through the grid was to decrease by 5%, the state would see benefits of between \$272 million to \$329 million through decreasing the amount of power lost in transmission. These values correspond do an emissions reduction of 1,788,500 MMT.

However, given that the combination of federal and state subsidies in California already make BloomBoxes attractive, it seems the limiting factor is people’s unfamiliarity with the technology and their unwillingness to change from previous habits. This is especially likely to be the case since BloomBoxes produce the amounts of energy required of office buildings, and so uptake of the technology would require a willingness on the part of the business to change their ways, although Google, Ebay, and other companies in California are leading the way in this regard.

By decentralizing energy supply, California could reduce the need to invest in maintenance for the power grid while also experiencing the aforementioned benefits including reduced carbon dioxide emissions as a result of higher proportion of energy produced to energy reaching the end-user, increased reliability for the supply of electricity for the end-user and lower electricity costs for the end-user. From a policy perspective, if California wanted to help increase the uptake of SOFCs, it should consider investing in research and development that could extend the lifespan of the cells, thus decreasing the levelized cost of the SOFC as a source of energy. Even given the current specifications of fuel cells, and the BloomBox in particular, and California’s stated aims at reducing emissions, it is clear that there is a role that can be filled by using the BloomBox to meet power generation requirements in the long-term future.

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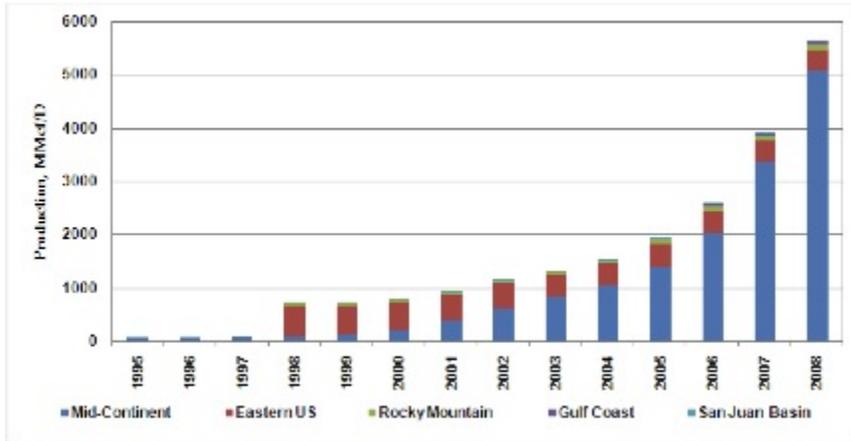
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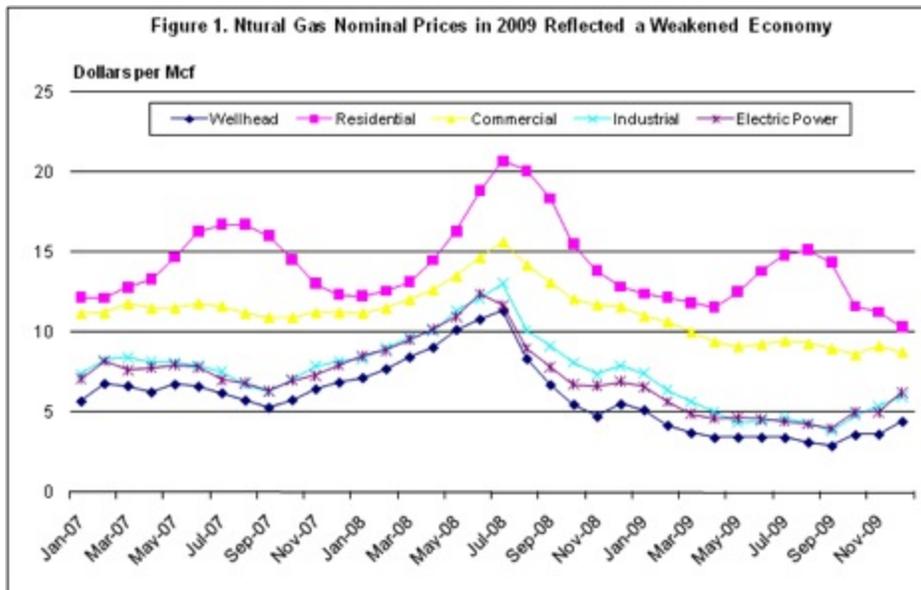
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Appendix

Natural Gas Market



Source: U.S. Energy Information Administration



Big Bold #s are changeable values

(changing most things requires checking financing payment-schedule if payment is not all up front)
(notes are marked with asterisks are addressed at bottom of page)

notes at end of section
marked with ***

Avg Price NG	6.67 \$	StandDev	2.11	National Average NatGas	Sheet1
NG	1000 CF			***1 highest July 2008	13.05
				***1 lowest Aug 2009	4.3
BloomBox stats	0.661 MMBTU	1,000,000 BTU	1 CF	Price of Natural Gas for power generation	100 KW
	1 hour	1 MMBTU	1000 BTU	8.34 \$	
# of units in system	10			Price Electricity via BB	0.055 \$
use KW/H	1000				
hours/ day	24				
days/ year	365.25	8,766,000 KWH/year		Cost/unit	800,000
lifetime of BB years	10.00				
hours of use for system	87,660,000 KWH				
Cost standard Elec	87,660,000 KWH	***4	Commercial price for Electricity	10,992,564	
Cost Elec w/ Bloom Box	87,660,000 KWH		0.1254 \$/KWH	4,832,468	
Savings from Elec w/ BB	87,660,000 KWH		0.0703 \$/KWH	6,160,096	
From Fuel			5600000 0.0703	79,689,666 \$	
(Not including system cost)			Cost of SOFC/Marginal difference after rebates C.Grid - C.Gas	9.0906	

rebate on system/W	0	1000	8000	Total system	8,000,000
		1000	0		8,000,000
Federal rebate	30.00%	8000000	2,400,000	Capital Cost of SOFC system	8,000,000
				rebates on system for capacity generation	0
				additional rebates/grants (flat)	2,400,000
				Additional Cost of SOFC (maintenance) NPV	0
				Cost of Financing NPV	0
				Cost SOFC system after rebates, financing and maintenance	5,600,000 \$
					87,660,000 KWH
				Hours of Operation	63,883,18503
				production capacity cost	0.0639 \$
				Cost of Electricity	0.1254
				\$10,992,564 Grid	
				\$10,432,468 BB gen	
				Using a discount rate of	7.00%
				Total Savings (or cost) of using SOFC compared to Grid (Not Discounted)	\$560,096
				Discounted Savings/Cost for yearly discounted savings/cost look below at NPV table	\$420,925
				This is just for cost reduction in electricity usage no factor for reduction in natural gas usage in heat applications	

Financing payment schedule

beginning Year	liability value	paid on liability	interest accrued	value liability	NPV of Yearly Payments	NPV of Financing + initial	NPV of financing - initial
0	5,600,000	5,600,000			5,600,000	5,600,000	0
1	0	0			5,600,000	5,600,000	0
2	0	0			5,600,000	5,600,000	0
3	0	0			5,600,000	5,600,000	0
4	0	0			5,600,000	5,600,000	0
5	0	0			5,600,000	5,600,000	0
6	0	0			5,600,000	5,600,000	0
7	0	0			5,600,000	5,600,000	0
8	0	0			5,600,000	5,600,000	0
9	0	0			5,600,000	5,600,000	0

NPV of Financing

\$0

Maintenance & Set-Up and Insurance

beginning Year	Yearly Costs	disc rate	Cumulative
0	0	1.07	0
1	0	1.07	0
2	0	1.07	0
3	0	1.07	0
4	0	1.07	0
5	0	1.07	0
6	0	1.07	0
7	0	1.07	0
8	0	1.07	0
9	0	1.07	0

Maintenance Costs are not generally known for Fuel Cells.

Differences in using Grid versus MethSOFC with NPV

beginning Year	disc rate	Cost of MSOFC elec gen \$/KWH	Avg cost MSOFC elec gen \$/KWH	Cost of grid elec \$/KWH	Grid-marg MSOFC Difference	Grid-AvgCost Difference	AvgCost SOFC/GRID NPV
0	1.07	0.0551	0.0639	0.1254	0.1254	0.1254	0.9490
1	1.07	0.0551	0.1190	1,099,256	1,099,256	616,010	56,010
2	1.07	0.0515	0.1172	1,027,342	2,126,599	1,191,720	108,355
3	1.07	0.0482	0.1039	911,212	2,929,458	1,729,766	157,276
4	1.07	0.0450	0.0971	851,600	3,781,056	2,232,614	202,997
5	1.07	0.0421	0.0908	795,888	4,576,944	2,702,564	245,726
6	1.07	0.0393	0.0849	743,821	5,320,765	3,141,771	285,660
7	1.07	0.0367	0.0793	695,159	6,015,924	3,552,244	322,982
8	1.07	0.0343	0.0741	649,682	6,665,606	3,935,864	357,862
9	1.07	0.0321	0.0693	607,179	7,272,785	4,294,387	390,480
	1.07	0.0300	0.0647	567,457	7,840,242	4,629,455	420,925
	1.07	0.0551	0.1190	1,043,247	8,883,489		

Notes

- ***1 National averages for Natural Gas prices obtained from <http://www.eia.doe.gov/dnav/ng/hist/n3045ca3m.htm>
- ***2 Average interest bank Prime interest Rate For 2008 obtained from <http://www.forecasts.org/data/data/MPRIME.htm>
- ***3 Discount rate average 1st through 3rd quarters 2008 <http://www.federalreserve.gov/releases/cpr/> (after 4th quarter 2008, discount rates < 0.5%)
- ***4 Prices for Electricity and Natural Gas for power generation are best observed through individual markets California Gas prices <http://www.eia.doe.gov/dnav/ng/hist/n3045ca3m.htm> California Electricity Prices http://www.eia.doe.gov/cneal/electricity/st_profiles/california.html http://www.eia.doe.gov/cneal/electricity/st_profiles/sep08ca.xls One should determine if users are using natural gas for producing electricity on site (via a NG Generator) or buying directly from the grid. (within the whole U.S. for 2010, price difference from Elect production and industrial use averages to ~ \$0.045 per 1000 CF of NG, or ~200%) (but price differences between in use of NG for industrial and electrical production are much less) The initial prices used are average prices in both Commercial use of Electricity and Natural Gas for Power Generation in CA for 2008 (These figures are not weighted for increased or decreased use between different months) (For 2008 CA NG prices were peaked in June/July, presumably for higher use of NG for electricity production to power air conditioners)
- ***5 Federal Investment Tax Credit or Production Tax Credit of 30%, with renewable energy sources receiving additional tax credits. <http://www.energy.gov/additionaltaxbreaks.htm> http://www.dsireusa.org/incentives/incentive.cfm?incentive_Code=US02F
- ***6 The \$2.5 per watt produced figure is from the Center for Sustainable Development of California for their incentive to use decentralized generation. <http://energycenter.org/index.php/incentive-programs/self-generation-incentive-program>
- ***7 "Mr. Sridhar contends the Bloom boxes, with reasonable maintenance, will have a 10-year life span." http://www.nytimes.com/2010/02/24/business/energy-environment/24bloom.html?_r=1
- ***8 Fuel Consumption based on Bloom Energy technical specifications. http://c0688662.cdn.cloudfiles.rackspacecloud.com/downloads_pdf_Bloomenergy_DataSheet_ES-5000_1.pdf

Big Bold #s are changeable values

(changing most things requires checking financing payment-schedule if payment is not all up front)
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notes at end of section
marked with ***

Avg Price NG	6.67 \$	StandDev	2.11	National Average NatGas	13.05	Sheet1
NG	1000 CF			***1 highest July 2008	4.3	
				***1 lowest Aug 2009		
BloomBox stats	0.661 MMBTU	1,000,000 BTU	1 CF	Price of Natural Gas for power generation	8.34 \$	= 100 KW
	1 hour	1 MMBTU	1000 BTU			
# of units in system	10			Price Electricity via BB	0.0551 \$	= 1 KW-H
use KW/H	1000					
hours/day	24			Cost/unit	800,000	
days/year	365.25	8,766,000 KWH/year				
lifetime of BB years	10.00					
hours of use for system		87,660,000 KWH				
Cost standard Elec		Hours of use		Commercial price for Electricity		
Cost Elec w/ Bloom Box		87,660,000 KWH	***4	0.1254 \$/KWH	10,992,564	
Savings from Elec w/ BB		87,660,000 KWH		0.0551 \$/KWH	4,832,468	
From Fuel				0.0703 \$/KWH	6,160,096	
(Not including system cost)				8000000 0.0703	113,842,380 \$	
				Cost of SOFC/Marginal difference after rebates C.Grid - C.Gas	12.9868	Years of operation to net out to 0

rebate on system/W	0	KWH	1000	\$/KW	8000	Total system	8,000,000
			1000		0		8,000,000
Federal rebate	0.00%	8000000					0
						8,000,000 Capital Cost of SOFC system	
						0 rebates on system for capacity generation	
						0 additional rebates/grants (flat)	
						0 Additional Cost of SOFC (maintenance) NPV	
						0 Cost of Financing NPV	
						Cost SOFC system after rebates, financing and maintenance	
						8,000,000 \$	= 0.0913 \$
						87,660,000 KWH	KWH
						Hours of Operation	
							91.2616929
						Commercial price for Electricity	
						0.1254	
						\$10,992,564 Grid	
						\$12,832,468 BB gen	
						Price Elec via MethSOFC	
						Fuel + Prod.Cap.Cost /KWH	
							Using a discount rate of 7.00%
							-1,382,731
						Total Savings (or cost) of using SOFC compared to Grid (Not Discounted)	
							Discounted Savings/Cost for yearly discounted savings/cost look below at NPV table
							This is just for cost reduction in electricity usage no factor for reduction in natural gas usage in heat applications

Financing payment schedule

beginning Year	liability value	paid on liability	interest accrued	value liability	NPV of Yearly Payments	NPV of Financing + initial	NPV of financing - initial
0	8,000,000	8,000,000			8,000,000	8,000,000	0
1	0				0	8,000,000	0
2	0				0	8,000,000	0
3	0				0	8,000,000	0
4	0				0	8,000,000	0
5	0				0	8,000,000	0
6	0				0	8,000,000	0
7	0				0	8,000,000	0
8	0				0	8,000,000	0
9	0				0	8,000,000	0

NPV of Financing

\$0

Maintenance & Set-Up and Insurance

beginning Year	Initial Cost of System	yearly rate of replacement	Set up cost	NPV M.S.I.
0	8,000,000	0	0	0
1		Yearly Costs	disc rate	Cumulative
1	0	0	1.07	0
2	0	0	1.07	0
3	0	0	1.07	0
4	0	0	1.07	0
5	0	0	1.07	0
6	0	0	1.07	0
7	0	0	1.07	0
8	0	0	1.07	0
9	0	0	1.07	0

Maintenance Costs are not generally known for Fuel Cells.

Differences in using Grid versus MethSOFC with NPV

beginning Year	discount rate	Cost of MSOFC elec gen\$/KWH	Avg cost MSOFC elec gen\$/KWH	Cost of grid elec\$/KWH	Grid-margMSOFC Difference	Grid-AvgCost Difference	AvgCost SOFC/GRID NPV
0	1.07	0.0551	0.0913	0.1254			
1	8,766,000	0.0515	451633	934,879	0.1254	1,099,256	1,099,256
2	8,766,000	0.0482	422086	1,356,966	0.1172	1,027,342	2,126,599
3	8,766,000	0.0450	394473	1,751,439	0.1095	960,133	3,086,732
4	8,766,000	0.0421	368667	2,120,106	0.1024	897,321	3,984,053
5	8,766,000	0.0393	344548	2,464,654	0.0957	838,617	4,822,670
6	8,766,000	0.0367	322008	2,786,662	0.0894	783,755	5,606,425
7	8,766,000	0.0343	300942	3,087,604	0.0836	732,481	6,338,906
8	8,766,000	0.0321	281254	3,368,858	0.0781	684,562	7,023,467
9	8,766,000	0.0300	262854	3,631,712	0.0730	639,777	7,663,244
	8,766,000	0.0551	483247	4,114,959	0.1464	1,283,247	10,927,144

Notes

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- ***6 The \$2.5 per watt produced figure is from the Center for Sustainable Development of California for their incentive to use decentralized generation. <http://energycenter.org/index.php/incentive-programs/self-generation-incentive-program>
- ***7 "Mr. Sridhar contends the Bloom boxes, with reasonable maintenance, will have a 10-year life span." http://www.nytimes.com/2010/02/24/business/energy-environment/24bloom.html?_r=1
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				***1 lowest Aug 2009		
BloomBox stats	0.661 MMBTU	1,000,000 BTU	1 CF	Price of Natural Gas for power generation	8.34 \$	
	1 hour	1 MMBTU	1000 BTU		100 KW	
# of units in system	10			Price Electricity via BB	0.055 \$	
use KW/H	1000					
hours/ day	24					
days/ year	365.25	8,766,000 KWH/year		Cost/unit	525,675	
lifetime of BB years	10.00					
hours of use for system		87,660,000 KWH				

Cost standard Elec	87,660,000 KWH	Commercial price for Electricity	10,992,564	Commercial price for Electricity	0.1254	Cost of Electricity	59,967,480.2
Cost Elec w/ Bloom Box	87,660,000 KWH	0.0551 \$/KWH	4,832,468		0.1151	\$10,992,564 Grid	
Savings from Elec w/ BB	87,660,000 KWH	0.0703 \$/KWH	6,160,096	Price Elec via MethSOFC		\$10,089,218 BB gen	
From Fuel		5256750 0.0703	74,805,116 \$	Fuel + Prod.Cap.Cost /KWH			
(Not including system cost)		Cost of SOFC/Marginal difference after rebates C.Grid - C.Gas	8.5338			Total Savings (for cost) of using SOFC compared to Grid (Not Discounted)	\$903,349
			Years of operation to net out to 0				Using a discount rate of 7.00% \$678,888

rebate on system/W	0	1000	5257	Total system	5,256,750
Federal rebate	0.00%	5256750	0	Capital Cost of SOFC system	5,256,750
				rebates on system for capacity generation	0
				additional rebates/grants (flat)	0
				Additional Cost of SOFC (maintenance) NPV	0
				Cost of Financing NPV	0
				Cost SOFC system after rebates, financing and maintenance	0.0600 \$
				87,660,000 KWH	
				Hours of Operation	
				production capacity cost	

Financing payment schedule

beginning Year	liability value	paid on liability	interest accrued	value liability	NPV of Yearly Payments	NPV of Financing + initial	NPV of financing - initial
0	5,256,750	5,256,750	0	0	5,256,750	5,256,750	0
1	0	0	0	0	5,256,750	5,256,750	0
2	0	0	0	0	5,256,750	5,256,750	0
3	0	0	0	0	5,256,750	5,256,750	0
4	0	0	0	0	5,256,750	5,256,750	0
5	0	0	0	0	5,256,750	5,256,750	0
6	0	0	0	0	5,256,750	5,256,750	0
7	0	0	0	0	5,256,750	5,256,750	0
8	0	0	0	0	5,256,750	5,256,750	0
9	0	0	0	0	5,256,750	5,256,750	0

Maintenance & Set-Up and Insurance

beginning Year	Initial Cost of System	yearly rate of replacement	Set up cost	NPV M.S.I.
0	5,256,750	0	0	0
1		Yearly Costs	disc.rate	Cumulative
1	0	0	1.07	0
2	0	0	1.07	0
3	0	0	1.07	0
4	0	0	1.07	0
5	0	0	1.07	0
6	0	0	1.07	0
7	0	0	1.07	0
8	0	0	1.07	0
9	0	0	1.07	0

Differences in using Grid versus MethSOFC with NPV

beginning Year	discount rate 1.07			Cost of MSOFC elec gen \$/KWH 0.0551			Avg cost MSOFC elec gen \$/KWH 0.0600			Cost of grid elec \$/KWH 0.1254			Grid-margMSOFC Difference NPV Cumulative	Grid-AvgCost Difference NPV Cumulative	AvgCost SOFC/GRID NPV
	KWH / year	disc cost of marg NG	NPV M-SOFC	Cumulative	disc cost of avg NG	NPV avg cost	Cumulative	disc cost grid	NPV Grid	Cumulative					
0	8,766,000	0.0551	483247	483,247	0.1151	1,008,922	1,008,922	0.1254	1,099,256	1,099,256	616,010	90,335	0.9178		
1	8,766,000	0.0515	451633	934,879	0.1076	942,918	1,951,839	0.1172	1,027,342	2,126,599	1,191,720	174,759			
2	8,766,000	0.0482	422086	1,356,966	0.1005	881,231	2,833,071	0.1095	960,133	3,086,732	1,729,766	253,661			
3	8,766,000	0.0450	394473	1,751,439	0.0940	823,581	3,656,651	0.1024	897,321	3,984,053	2,232,614	327,401			
4	8,766,000	0.0421	368667	2,120,106	0.0878	769,702	4,426,353	0.0957	838,617	4,822,670	2,702,564	396,317			
5	8,766,000	0.0393	344548	2,464,654	0.0821	719,347	5,145,700	0.0894	783,755	5,606,425	3,141,771	460,724			
6	8,766,000	0.0367	322008	2,786,662	0.0767	672,287	5,817,988	0.0836	732,481	6,338,906	3,552,244	520,918			
7	8,766,000	0.0343	300942	3,087,604	0.0717	628,306	6,446,293	0.0781	684,562	7,023,467	3,935,864	577,174			
8	8,766,000	0.0321	281254	3,368,858	0.0670	587,202	7,033,495	0.0730	639,777	7,663,244	4,294,387	629,750			
9	8,766,000	0.0300	262854	3,631,712	0.0626	548,787	7,582,282	0.0682	597,923	8,261,167	4,629,455	678,886			
	8,766,000	0.0551	483247	4,114,959	0.1151	1,008,922	8,591,203								

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