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Bloom's Energy Server™
Fuel Cell Technology for Green Innovation

Description:

Bloom's Energy Server™ (commonly referred to as a Bloom Box) is a privately owned technology for producing energy from solid oxide regenerative fuel cells.

Bloom Energy[1] (originally called Ion America) is a privately owned company founded in 2001 and based in Sunnyvale, CA. The principal Co-Founder and Chief Executive Officer of Bloom Energy, K. R. Sridhar, and his team worked on NASA's Mars space program at the University of Arizona in the 1990s and built a device capable of producing air and fuel from electricity and, reversibly, producing electricity from air and fuel. In 2001, after the NASA project was over, the team continued its research, which led to the formation of an innovative device—Bloom's Energy Server™—that serves as a clean, reliable, and affordable energy source.

The initial servers were made with the capacity to generate 5kW of electricity and were tested at a field trial site at the University of Tennessee in Chattanooga. Several other units were then tested in California and Alaska to validate the technology. The commercial (100kW) servers were shipped to the company's first customer, Google, in July, 2008.

As this alternative is still in its early development stage, Bloom Energy manufactures the commercial servers manually. The other early customers include FedEx, Coca-Cola, Staples, and Wal-Mart. Mass-manufacturing of small household units of the Bloom Energy Server™ is expected in the future, and it is expected that this will be an affordable option for energy production in domestic settings (private homes).

Technology and architecture of the Bloom Energy Server™:

Energy server: An energy server is an electricity generator that has the capacity to store the generated power. Bloom Energy uses its patented solid oxide regenerative fuel cell technology for its Energy Server™. Each server consists of thousands of Bloom's solid oxide regenerative fuel cells.

Fuel cells: Fuel cells are devices that convert fuel into electricity through a clean electro-chemical process without any combustion. This conversion technique gives much higher conversion efficiencies than conventional thermo-mechanical methods. The operating principles of fuel cells are similar to those of batteries; i.e., includes an electro-chemical combination of reactants to generate electricity—a combination of a gaseous fuel (hydrogen) and an oxidant gas (oxygen from the air) through electrodes and via an ion-conducting electrolyte. However, unlike a battery, a fuel cell does not run down or require recharging. A fuel cell operates as long as both fuel and oxidant are supplied to the electrodes, and the influence it exerts on the

surrounding environment is negligible (see Resources section for links to more information on fuel cells).

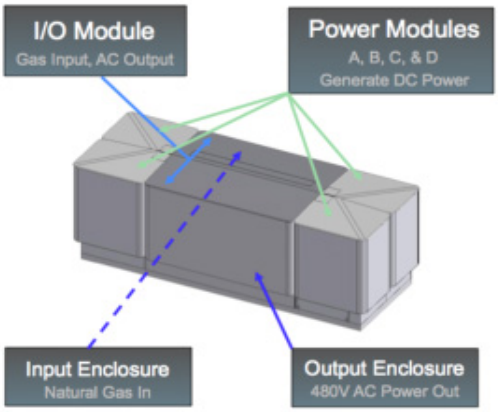
Solid oxide fuel cell (SOFC)[1,2,3]*:* A SOFC is a type of fuel cell valued for its potential market competitiveness, with high efficiency in fuel input and electricity output. A SOFC is like a rechargeable battery that always runs. It consists of three parts: an electrolyte, an anode, and a cathode. In Bloom's SOFC, the electrolyte is a solid ceramic square made from a common sand-like "powder." According to Bloom's patent description, these thin white ceramic plates are Scandia stabilized Zirconia (ScSZ). The anode and cathode are made from special inks that coat the electrolyte on each side. One side of the ceramic electrolyte plate is coated with a green nickel oxide-based ink that works as an anode; the other side, which works as a cathode, is coated with black ink (most probably Lanthanum Strontium Manganite—a non-radioactive substance). The Bloom server does not require chemicals, such as the corrosive acids used in conventional fuel cells. Instead, it uses inexpensive metal alloy plates for electric conductance between the two ceramic fast-ion conductor plates, as opposed to the use of costly precious metals like Gold or Platinum that are used for high conductance in other fuel cells.

The electro-chemical process within SOFC (http://www.bloomenergy.com/products/solid-oxide-fuel-cell-animation/):

SOFC requires a high operating temperature (600-1000^{0}C) for its reactions to take place. At a high temperature, warm air enters the cathode side of the fuel cell. The resulting steam mixes with the fuel to produce reformed fuel; this reformed fuel enters the anode side, and a chemical reaction takes place. As the reformed fuel crosses the anode side, it attracts oxygen ions from the cathode. Oxygen ions combine with the reformed fuel to produce electricity, water, and a small amount of carbon dioxide gas. Water is recycled into the cell to produce steam to generate reformed fuel, and this process also generates the heat required for the functioning of fuel cells. The continuous supply of fuel, air, and heat constantly generates the electricity from the cell.

Each Bloom Energy fuel cell is capable of producing about 25W of energy, which is enough to power a light bulb. For more power, multiple cells are mounted together, along with metal interconnect plates, to form a fuel cell stack. A few stacks together (about the size of a loaf of bread) are enough to power an average U.S. home. In an Energy Server™, multiple stacks are aggregated into a "power module"; and multiple power modules, along with a common fuel input and electrical output, are assembled as a complete system. When more power is required—for example, for commercial or industrial sites—multiple Energy Server™ systems can be deployed side by side. The current Energy Server™ in the market has the capacity to generate 100kW of electricity, which would power a 30,000 sq. ft. office building or 100 average-sized U.S. homes.

Bloom Energy Server™ Unit Design[4]



Cost of Bloom Energy Server™:

The current 100 kW Bloom Energy Server™ costs approximately $700,000–$800,000. The high cost is the result of the factors associated with manual production, and these production costs are expected to come down once mass-manufacturing starts and widespread commercial and domestic use becomes routine practice. Bloom Energy estimates the size of a home-sized server as 1 kilowatt, and it is expected to cost under $3000.

End-use is more cost-effective compared to other sources of generated electricity. Bloom's servers produce significantly more electricity for the same fuel costs of conventional energy sources, and the Bloom server's ability to generate the electricity on-site eliminates the need for costly transmission and distribution infrastructure. Thus, savings typically provide a three-to-five-year payback on a user's initial capital investment.

While individual commercial or industrial sites or individual homeowners can purchase their own servers to generate electricity on site and, thereby, put control directly into the consumer's hands, Bloom Energy suggests an alternative means of achieving the cost-savings of the Bloom Energy Server™— selling the electricity produced by the server (named Bloom Electrons℠) rather than selling the server itself. Both small energy suppliers and big energy industries can invest in a Bloom server and make their generated electricity available to individual consumers. This shifts the cost of infrastructure management from individual consumers to the suppliers.

Industry comparisons:

The Bloom Energy Server™ is a relatively recent entry into the field of "green and affordable energy"; it is not yet available for home use, and mass-production has not yet been achieved for commercial use. Thus, comparison claims with other green energy alternatives (such as wind, solar, and other types of fuel cells) are difficult to substantiate. In addition, continued progress in research and

development continues to improve technology and output and to reduce costs for a variety of green energy alternatives, including the Bloom Box. When comparing this innovative model with other modes of green energy, professionals note that insufficient "use-time" has elapsed for evaluations of the Bloom server equipment's long-term durability and reliability, the model's aggregated carbon dioxide emissions once mass-production is achieved, its comparative electricity-generation conversion efficiency, and its potential to surpass other models' production and operation costs.

References:

[1] Bloom Energy: http://www.bloomenergy.com/.

[2] Wikipedia (April 12, 2011), "Bloom Energy Server": http://en.wikipedia.org/wiki/Bloom_Energy_Server.

[3] A. B. Stambouli and E. Traversa (October, 2002), "Solid oxide fuel cells (SOFCs): a review of an environmentally clean and efficient source of energy," *Renewable and Sustainable Energy Reviews;* Vol. 6, Issue 5, Pages 433-455.

[4] Bloom Energy (retrieved April, 2011), "Energy Server Architecture," *Bloomenergy*: http://www.bloomenergy.com/products/architecture/.

Benefits:

Multipurpose use:

- SOFCs have been successfully used for military purposes and for U. S. space programs. Following Bloom's development of the energy server system at the University of Arizona for NASA's Mars Space Mission, Bloom has brought SOFC technology into commercial and industry use, and development for domestic use as a portable energy source is expected in the future.

- Urban, suburban, and rural use: The Bloom server's modular architecture, solid state construction, portability, and easy-to-install units allow for flexible assembly and make the systems suitable for any geographic area.

For the overall community and the environment:

- A green energy alternative:
  - With the Bloom Energy system, Carbon Dioxide (CO_2) emissions are reduced by 40%-100% compared to the U.S. grid (depending on their fuel choice), leading to a reduction in the nation's carbon footprint in affordable ways.
  - There is virtual elimination of all harmful gases (SOx, NOx, etc.) and other harmful smog-forming particulate emissions.
  - Bloom Energy systems emit pure CO_2, which allows for easy and cost-effective carbon sequestration (separating the CO_2 from the other effluents).
  - The system does not use any harmful chemicals, such as acids or alkalis, which are used in other fuel cells.
  - Bloom's servers produce no noise pollution, which can be present in other energy production facilities.

- Local decision-making:
  - Multiple local production and distribution options: Individual companies or homeowners can choose to individually own a server to generate their own electricity, or a municipality or generation facility can own a server system to generate and distribute electricity (Bloom Electrons℠) to multiple business and homeowner customers.
  - The Bloom Energy system puts energy-generation control into the customers' hands, allowing them to manage their energy sources more effectively.

- Financial incentives, subsidies, and tax credits may be available to green energy users, depending upon a state's energy policies and available federal programs.

For commercial, industrial, and domestic consumers:

- Production and distribution efficiency:
  - Solid Oxide Fuel Cells (SOFCs) are the most efficient in fuel input and electricity output due to their high operating temperature (800^0C). SOFC technology in Bloom's servers is about twice as efficient in energy production compared to standard power sources.
  - On-site power generation and storage allows for an efficient power supply, eliminating the costs, complexities, interdependencies, and inefficiencies associated with conventional transmission and distribution systems, and also reducing the geographical strain.

- Lower cost:
  - Bloom's servers do not use expensive noble metals like Platinum or Gold, thus reducing production constraints and costs.
  - Reverse backup and high return on investments: For businesses using Bloom's servers, the system works as the primary source of their energy supply, with other conventional sources, such as grid power, acting as a backup to supplement energy output when necessary. This increases asset utilization, gives a high return on investment, and reduces the cost of purchasing and maintaining expensive generators and other backup applications.
  - The servers produce significantly more electricity for the same fuel costs compared to conventional sources, due to the efficient conversion of fuel to electricity.
  - The servers can operate with multiple fuel options, such as renewable fuels (e.g., biogas) or fossil fuels (e.g., natural gas). Depending on the availability of the local fuel source, customers can choose the cheapest fuel to maintain the system's economy.

- Reliability and durability:
  - Since Bloom systems are capable of running on a wide range of pipelines and locally stored fuels and can automatically detect an interruption, they can cut over from a primary to a backup fuel source and maintain a continuous power supply.

- The system generates perfect waveform (voltage or electrical flow) at the point of consumption, eliminating volatility and allowing perfect power quality without variations in voltage, intermittent brown-outs, or black-outs.
- Long term use: SOFCs have a potential life expectancy of 40,000–80,000 hours.
- Bloom's energy systems work 24*7*365, for a continuous production and supply of energy.
- Independence from natural resources: SOFC technology and Bloom Energy Servers™ do not depend on natural resources (such as wind, sunlight, or the force of water currents) for the production of electricity, which allows quick access to the power supply with uninterrupted service.
- The heat produced within the server's electro-chemical process is recycled within the cell and external loss of heat is minimized by the strong protective shield.

Impediments or barriers to development or implementation:

- Criticism and skepticism have been expressed by members of conventional energy industries that are using standard practices.

- The current manual production of Bloom server systems requires significant start-up time.

- Currently, the server systems are marketed only for commercial use, with mass production for domestic units expected as a future market.

- The present high cost of equipment (because of manual production) is currently affordable to big industries only.

- Economic and other technical analyses are needed to establish market standards.

- Evaluation of the aggregate level of CO_2 emissions will be needed when mass-energy production for wider use takes place.

- Technical challenges:
  - Requires very high operating temperature.
  - Highly sensitive to operating temperature variation.
  - High temperature demands significant thermal shielding to protect personnel and to retain heat.

Resource—examples:

- *Coca-Cola Company, Atlanta, GA:* The Coca-Cola Company installed 500kW capacity Bloom Energy Servers at their Odwalla Production Facility at Dinuba, CA, in February 2010. Coca-Cola's "2020 Vision" is to double revenue and increase margins using sustainability approaches throughout their company. Through their servers, Bloom Energy has provided a flexible solution that can provide constant, reliable power to Coca-Cola's around-the-clock bottling and manufacturing operations, provide a power-dense solution to large office

buildings, and make a major contribution to reducing greenhouse gas emissions in the company's facilities. Coca-Cola's objective is to operate on renewable biogas, providing a 24/7/365 renewable solution at its Odwalla Production Facility and reducing over 5 million pounds of CO_2 annually.
  - Odwalla Facility: http://www.thecoca-colacompany.com/dynamic/press_center/2010/02/the-coca-cola-company-takes-important-step-toward-clean-power-in-us.html.
  - Elizabeth Delmont, Jennifer Gangi, and Sandra Curtin (November, 2011), *The Business Case for Fuel Cells: Energizing America*'s *Top Companies:* http://www.werc.org/assets/1/Publications/941%20BusinessCaseforFuelCells2011.pdf, see page 20 for profile of the Coca Cola Company.

- *Walmart, Bentonville, AR*: Walmart has installed two 400kW capacity Bloom servers, generating approximately 3.4 million kWh annually at their two facilities—Lancaster, CA, in December, 2009, and Hemet, CA, in January, 2010. Each of these sites has the potential to eliminate one million pounds of CO_2 annually when powered by biogas. Walmart's goal in using Bloom's servers is to achieve sustainability in its operations through the use of renewable energy sources and a reduction in greenhouse gases, and the company expects a reduction in energy expenses along with a reliable, continuous power supply. http://www.bloomenergy.com/customers/customer-story-walmart/.
  - The Walmart Community Action Network website blog attests to the installation of another server at its Dinuba, CA, location. http://www.walmartcommunity.com/two-dinuba-firms-rely-on-fuel-cells-coca-colas-odwalla-walmart-using-bloom-boxes/.

- *Cypress Semiconductor Corporation, San Jose, CA:* Cypress Corporation installed 300kW capacity Bloom Energy Servers at its San Jose, CA, headquarters in July 2010. These servers, combined with existing rooftop solar panel installations, supply approximately 75 percent of Cypress's electric needs. The company expects to be independent of the public utility grid by the year 2015, with a five-year payback period on its initial investment in three Bloom servers. http://investors.cypress.com/releasedetail.cfm?ReleaseID=484848.

- *Additional Bloom Energy industrial customers*: Information about the following customers of Bloom Energy's technology can be viewed on Bloom Energy's web site at http://www.bloomenergy.com/customers/#:
  - Google Inc., Mountain View, CA
  - California Institute of Technology (Caltech), Pasadena, CA
  - Staples, Framingham, MA
  - Abode Systems Incorporated, San Jose, CA
  - Kaiser Permanente, Oakland, CA
  - eBay Inc., San Jose, CA
  - FedEx Corporation, Memphis, TN
  - Bank of America Corporation, Charlotte, NC
  - Becton, Dickinson and Company (BD), Franklin Lakes, NJ
  - The University of Tennessee, Chattanooga Sim Center, Chattanooga, TN
  - COX Enterprises, Atlanta, GA

- Sutter Home Winery, St. Helena, CA
- Safeway, Inc., Pleasanton, CA

Resource—written and web:

- Bloom Energy*: Bloomenergy*: http://www.bloomenergy.com/.

- "Bloom Energy Server," *Wikipedia* (retrieved April 12, 2011), Wikipedia Foundation, Inc.: http://en.wikipedia.org/wiki/Bloom_Energy_Server/.

- *ScienceDirect* web site—list of resources, articles, and books on the Bloom Energy Server: http://www.sciencedirect.com/science?_ob=ArticleListURL&_method=list&_ArticleListID=2067027363&_sort=r&_st=4&_acct=C000228598&_version=1&_urlVersion=0&_userid=10&md5=02de97b88b9c67926f24ff0334aca0fe&searchtype=a.

- Marci Brunner (2010), "Fuel Cells," Article IV.2.h, *Livable New York Resource Manual,* Albany, NY: New York State Office for the Aging. http://www.aging.ny.gov/LivableNY/ResourceManual/Index.cfm/.

- Frank Mace (2010), "Renewable Energy and Distributed Generation," Article IV.2.m, *Livable New York Resource Manual,* Albany, NY: New York State Office for the Aging. http://www.aging.ny.gov/LivableNY/ResourceManual/Index.cfm.

- B. Stambouli and E. Traversa (October, 2002), "Solid oxide fuel cells (SOFCs): a review of an environmentally clean and efficient source of energy," *Renewable and Sustainable Energy Reviews*, Vol. 6, Issue 5, Pages 433-455.

- News coverage:
  - CBS New.com, *60 Minutes* (February 18, 2010), "The Bloom Box: An Energy Breakthrough?" video and news report: http://www.cbsnews.com/stories/2010/02/18/60minutes/main6221135.shtml.

  - Todd Woody (April 29, 2010), "The Greening of Silicon Valley: It Looks Like the Next Big Thing," *Report; environment360*, published by the Yale School of Forestry & Environmental Studies and Yale University, an online magazine offering opinion, analysis, reporting and debate on global environmental issues: http://e360.yale.edu/content/feature.msp?id=2269.