Nuclear fusion and Robert W. Bussard

Robert W. Bussard may have recently created knowledge that could lead to a rapid (15 years) development and deployment of large scale commercial generation of electricity by nuclear fusion. A safe and economical way of producing electrical energy from nuclear fusion would mitigate two of humanity's fateful dilemmas: the approaching rapid decline of oil and natural gas, and the need to eliminate the production of atmospheric greenhouse gases by human activity. Inexpensive fusion energy would eliminate any need for energy from fossil fuels or nuclear fission. Nuclear fusion, unlike nuclear fission, produces almost no waste products, and produces no long lived radioactive waste at all.

The universe is powered by nuclear fusion in stars. Nuclear fusion is the process by which two nuclei of atoms of lighter elements collide at very high speeds and combine to form a nucleus of an atom of a heavier element. Fusion requires extremely high temperatures, millions of degrees. (Temperature is a measure of the speed of atoms and other particles.) Continuing fusion reactions in a given volume require very hot matter -- fusionable nuclei -- to be confined in the volume as long as fusion reactions are to continue in it. In stars, gravity confines the reacting matter. Mutual gravitational attraction of the particles of the star acts on each particle with a resultant force pulling it toward the centre of the star. The gravitational force of the star is so great that the fast-moving particles in the fusion reaction at the centre of the star cannot escape from the star or blow it apart. Gravity cannot contain fusion reactions on Earth, because the force of gravity is too weak in bodies smaller than stars.

Producing useful energy from fusion on Earth presents three main problems: containing matter heated to millions of degrees in such a way that the necessarily cold container does not inhibit the hot fusion reaction, keeping the fusion reaction from destroying the container, and getting the desired energy of the reaction out of the container. The only means of confining a fusion reaction on Earth are inertia, electric fields, and magnetic fields. Inertial confinement is used in hydrogen bombs, and in at least one proposal for peaceful fusion. But confinement by electric and magnetic fields has long seemed more promising for peaceful nuclear fusion. Robert W. Bussard's contribution to fusion research is a particular confinement method that uses both electric and magnetic fields. His secret work during the 12 years to 2006 on a contract for the U.S. Defense Department has demonstrated that his confinement technique can create fusion. He claims that this work has also indicated that his tiny experimental reactors can be scaled up to produce utility scale electricity generators.

Bussard's company, Energy Matter Conversion Corporation (11 people, logo: EMC^2) worked in secret for 12 years until October 2006 on a DARPA contract, mainly for the US Navy, on experimental confirmation of a confinement method for a nuclear fusion power reactor. The confinement method was disclosed before this period of secret work by Bussard's 1989 patent, US patent 4826646, Method and Apparatus for Controlling Charged Particles. The operation of a fusion power reactor based on

Bussard's confinement method is described very clearly in the patent document. This 1989 patent describes the configurations and principles involved in the subsequent secret work. The patent may be understood with elementary knowledge of electricity and magnetism, elementary knowledge of atomic structure and ionization, and an elementary understanding of the basic facts of nuclear fusion. The description below provides an extremely brief précis of the patent and Bussard's recent paper.

The secrecy of the recent work seems not to have resulted from concern for national security, but from concern about the politics of funding. Bussard's project was run as a skunk works on tiny funding from the US Defense Advanced Research Projects Agency (DARPA). DARPA is not supposed to have responsibility for fusion, and it was thought by the DARPA contract officer that knowledge of the work by heavily funded competing projects would result in cancellation of the work. Bussard describes the funding politics in his talk (which was otherwise mainly technical) at Google Corporation in November 2006 (video, transcript). In any event, all of the work is now available, presumably subject to the commercial interests of EMC^2. Bussard has published a paper on the secret work, "The advent of clean nuclear fusion", in October 2006 at the International Astronautical Congress in Valencia, Spain.

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The Bussard confinement structure uses a pseudo-spherical magnetic field to confine a sphere of very energetic electron gas at the centre of the generally spherical containment structure. The whole containment structure is evacuated, containing only a good vacuum, the electrons, the reacting nuclei, the reaction products, some electromagnets, one or more electron guns, and ion guns for each reacting element. The reaction products are removed from the containment structure continuously.

The confining magnetic field is produced by a number of doughnut shaped electromagnets inside the vacuum of the containing structure. Each doughnut-shaped magnet is disposed on the face of a notional polyhedron having an even number of faces surrounding each vertex, e.g. an octahedron. The structures that encase and support the electromagnets must be conformal to the shape of the magnetic field produced by the magnet so that lines of force of the magnetic field do not intersect the supporting structures. For example, a magnet that produces a doughnut-shaped field must be enclosed by a doughnut shaped support. The magnets must not touch each other, because there must be sufficient room between the magnets so that particles guided by the magnetic field may escape from the centre without hitting the magnets. An even number of faces is required around each vertex so that the polyhedron can have electromagnets of opposite North-South polarity on each of the two faces adjacent at each edge. The resulting magnetic field confines a ball of electron gas at the centre of the polyhedron.

Since electrons are negatively charged, the ball of electron gas attracts and confines positively charged fusionable nuclei that fall into it. The magnetic field does not have to be strong enough to confine the heavy charged nuclei, only strong enough to contain the lighter electrons, even though both have the same temperature. The net charge of the combination of the electrons and the reacting (positive) particles is kept sufficiently negative so that this is true. There are always more electrons present in the ball than fusionable nuclei. Fusionable nuclei are allowed to fall into the attraction of the central ball of electrons from suitable sources (ion guns) inside the containment structure but outside the confining magnets. The electric field due to the concentration of negative electrons confines the positively charged nuclei that await a suitable collision after having been accelerated to fusionable temperature. The energy required to accelerate the fusionable particles into the electron gas sphere results from conversion of potential energy of the field into kinetic energy of the particles, but this loss of field potential energy is being replenished simultaneously by an equal current of positive charges on reaction products leaving the central ball, and being slowed by the field as they leave. There are losses of electrons and energy from the central ball not discussed here. The losses are made up by a stream of high energy electrons fired by an electron gun from outside the polyhedron into the ball along a "cusp" in the magnetic field in the centre of one of the faces of the polyhedron. The stream of negative electrons moves into the electron ball against the repelling force of the electron ball, adding energy into the potential of the field of the ball.

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The Bussard configuration can confine extremely hot fusion reactions. This means a Bussard reactor can support fusion reactions that involve the heavier light elements, like boron. Hydrogen-boron fusion ($p + {}^{11}B \Rightarrow 3\ {}^{4}He$) is particularly attractive for generating electricity. Since it usually produces only three helium (He) nuclei and no neutrons, it produces very little radiation. It occurs as the result of a very energetic (hot) collision between a proton (p, the nucleus of an ordinary hydrogen atom) and the nucleus of an atom of boron (${}^{11}B$ - the isotope of boron with atomic weight 11). Boron is very common in nature. A compound containing boron is present in many laundry detergents as a whitening agent. The isotope ${}^{11}B$ needed for the fusion reaction comprises about 80 percent of naturally occurring boron, the other 20% being ${}^{10}B$.

The very fast positively charged helium nuclei that result from hydrogen-boron fusion can easily escape the electrostatic field that contains the (also positively charged) protons and boron nuclei that have not yet fused. The positively charged helium nuclei strike a positively charged grid enclosing the magnets and the ball of electrons and reacting nuclei. The positively charged helium nuclei have to travel "up hill" against the electrostatic field established between the negative central gas ball and the positive grid. This up hill travel converts the mechanical energy due to their high speed into electrical potential energy. At the grid they are provided with electrons from an external electrical circuit, turning them into complete helium atoms, neutralizing them and establishing the current in the external circuit that is the desired product of the fusion reaction. A vacuum pump removes the resulting helium gas continuously. Bussard estimates that the efficiency of conversion of the kinetic energy of the He nuclei into electrical potential energy would be about 85%. As a result, the waste heat from a direct conversion hydrogen-boron electricity generating plant would be only a tenth of that produced by thermal plants powered by burning coal, nuclear fission, or fusion processes that generate neutrons. A direct conversion hydrogen-boron fusion plant is relatively compact. It is suitable for electrical propulsion of ships, as well as for electrical utility generation.

Other fusion reactions, also well supported by the Bussard reactor configuration, produce very large numbers of neutrons. Such reactions may be more suitable for retrofitting existing commercial coal and nuclear generating plants, since they can efficiently generate large amounts of steam to feed the existing turbines.