ECOFusion – Production of Clean Nuclear Power

Nuclear fusion has long been considered the best hope for mankind's energy needs. The reactions studied the most are those that take elements of hydrogen and fuse them to produce helium. Such reactions are known to produce about 10 million times more energy than chemical reactions, and since water contains hydrogen, the available fuel supply is essentially inexhaustible. A fusion reactor will produce no greenhouse gases and will not be susceptible to run-away nuclear accidents. A fusion reactor will not involve materials used in fission bombs, and they will produce far less nuclear waste than fission reactors. For these reasons, significant research efforts have been made over the past fifty years in order to reap the many benefits fusion energy could provide.

Presently, world-wide fusion research predominantly focuses on the use of plasma devices. In a plasma, hydrogen gas is heated to such a high temperature that the electrons and the nuclei are freed from each other, and the resulting charged particles can be contained by magnetic fields. The original hope was that the temperature and density of the plasma could be increased enough to make enough fusion occur to operate a power plant. Unfortunately, present devices cannot achieve the desired parameters due to particle losses caused by the particles scattering off of each other.

ECOFusion is a new approach. Rather than trying to heat a plasma to a high temperature so that a small percentage of the hydrogen has the right velocity to maximize fusion, the ECOFusion approach directly accelerates beams of hydrogen and focuses them into collision at the optimum conditions for fusion to occur. Hence, ALL of the hydrogen will have the correct conditions, rather than a few percent. Yet, even with such an effort, most of the hydrogen will not fuse, and if the energy put into those particles was simply thrown away, it is easy to show that the ECOFusion approach would not create enough energy to maintain itself. Hence, it is critical that those particles that do not fuse are contained in the device for additional passes. Storing particles for many passes is subject of the accelerator physics of storage rings.

Storage rings have been operated for decades to study the physics of exotic particles. Typically, the energy of the beams is very high, and the currents very low. Hence, while these devices routinely produce fusion events, the amount of energy released is miniscule. Nonetheless, the science of storage rings has identified many of the factors needed to contain particle beams for large periods of time. Important issues include particles scattering off of one another in the same beam, particles scattering off of the oncoming beam, and particle interactions with the electromagnetic fields of the beams and exterior devices such as magnets. The science of ion optics, which allows for calculation of the magnetic fields needed to contain the beams, is well established.

Central to achieving long lifetimes for beams in storage rings is the concept of beam cooling. Beam cooling is the process whereby errors in particle trajectories are corrected in some way. Synchrotron radiation is a natural process that can be used at high energies. Stochastic cooling uses electrodes to apply the right kicks and is affective at correcting trajectories for low intensity beams. Electron cooling works by superimposing a single pass electron beam on top of an ion beam, with the ion trajectories corrected by scattering losses to the electron beam. Electron cooling works best for low energy beams, such as those needed for fusion.

It may at first appear that ECOFusion will be too large and expensive to be practical, since a gigawatt power plat using ECOFusion would require thousands of particle accelerator storage rings, each storing 10 kA of ion beams. But the important point is that each of these storage rings are quite small by accelerator standards, measuring 3 meters by 1 meter by 22 meters in the most recent thorough design. Hence, as per the present prototype design, a 1 GW plant would be about 220 meters by 219 meters by 24 meters, not too different from present coal fired power plants. And while the cost to build the first ECOFusion prototype is quite high, that is because of all of the scientific and engineering manpower required for initial construction. Once the technology becomes well understood each ECOFusion module will be identical to the next, allowing for mass production. Once in mass production mode, module costs will approach the cost of the materials needed for construction. With design improvements it is expected that the output of a single ECOFusion module can eventually reach 300 kW, and at that output level ECOFusion production devices should cost under $1 per Watt. That production cost, along with the very low cost of fuel, should make ECOFusion extremely cost effective in the long term.

ECOFusion is a modular approach to fusion that has numerous advantages over other approaches: 1) In the research phase, we can build and test a fully functional, full scale module. We won't have to build a bigger one later to achieve useful commercial power levels, with uncertainties involved in scaling. Rather, we'd just build a lot of the same thing over and over again. 2) Operationally, if one unit goes out, you only lose a small portion of your generating capacity. 3) If the power plant needs to reduce generating capacity (or ramp it up) it would only need to turn off (or turn on) some of the modules in the system. 4) Should modules require periodic maintenance, a small portion of the modules could be cycled out of and back into service on a rotating basis. 5) The granularity of each module can allow for fusion power to be generated in 300 kW generators for mobile needs, while also at GW levels for power plant needs, or any size in between, making ECOFusion a highly versatile approach of using fusion for energy generation.

Dr. Delbert Larson received his Ph.D. in accelerator physics from the University of Wisconsin, with his thesis topic being electron cooling for antiprotons. He went on to work in various national laboratories and universities, and eventually became the lead accelerator physicist on Fermilab’s PET project where he designed and led the construction effort of a 1 MeV He-3 accelerator. The PET device worked just as it was designed. He has spent the past seven years researching the idea of ECOFusion, which applies electron cooling to fusion energy generation. The ECOFusion design used the same tools and methods used in the successful PET effort, analyzing all of the various scattering processes that can cause difficulty. Presently, the ECOFusion design predicts that the device will produce ten times more energy out than the energy input required to operate the device.

Dr. Larson presented ECOFusion at a scientific conference in Washington, DC in 2007. (See http://www.physicsessays.com/symposium2007.asp for details.) He has one patent pending, one issued, and is presently looking for funding, with $10-15 M needed for full prototype construction. Figure 1 shows a diagram of the present ECOFusion design. Dr. Larson is presently a Research Professor of Physics at UT-Arlington.

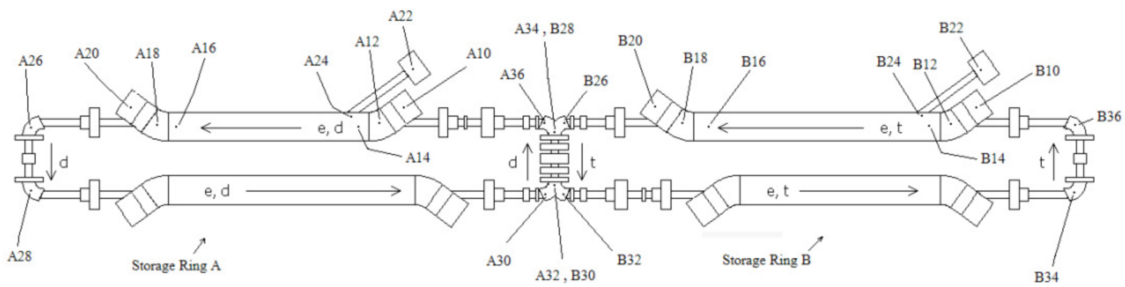

Figure 1. Conceptual Drawing of the ECOFusion Approach. Deuterons (d) and tritons (t) are formed in ion sources and then injected into separate storage ring systems that contain a mutual overlapping straight section. Electron beams are overlapped onto the ion beams in the long straight sections of the storage rings. The ions will lose their momentum errors to the electron beam in these cooling sections. The electron beams are brought into and out of the cooling region with solenoidal and torroidal fields. As the ions travel around the individual storage rings they are eventually brought into collision with each other in the interaction region in the center of the diagram. Edge angles, quadrupoles and solenoids are used to focus the beams within the storage rings. The figure shows an ECOFusion configuration involving two colliding beam systems. The ion beams continue to circulate within the two storage rings, with a continual increase in beam currents until very large ion beam currents are obtained and useful fusion output power levels are obtained.

An ECOFusion Project Plan.

1. Phase One

1.1. Phase One Technical Objectives.

The first objective of Phase One is to build and test a 100 Ampere, 50 eV electron cooling system. This system will involve construction and testing of an electron gun, an electron collector, and a solenoidal transport region between the gun and collector. The gun, collector and solenoid will predominantly use standard state of the art technology. The exception to standard state of the art will be a novel reverse-biasing of electrodes within the system. This back biasing will provide a longitudinal electric trapping field for ions, which, in conjunction with the radial trapping enabled by the solenoid, will allow for a complete trapping of ions (patent pending). This trapping will enable a neutralization of the electron beam self-electric fields and will enable a large increase in the amount of low energy electron current over more traditional approaches. Construction and testing of this system will provide a proof of principle for the larger systems needed for the ECOFusion prototype.

The second objective of Phase One is to prepare and submit additional patents that have been identified from previous ECOFusion work. This effort will provide additional protection for the intellectual property of ECOFusion which is essential for attracting future private sector investment.

The third objective of Phase One is to design a small storage ring for Phase Two. The small storage ring design will use dipole, quadrupole and solenoid magnets appropriate for the end regions of a full ECOFusion cell, but it will not have a colliding beam region. The storage ring will use the cooling system built during Phase One.

1.2. Phase One Cost Proposal.

Phase One Cost and Duration – $500 K, 9 months.

Cost Breakdown - Patent expenses, $30 K, cathode and grid purchases $20 K, beampipe, ceramics and stands $40 K, vacuum pumps (rougher and ion pump) $20 K, power supplies and control racks $10 K, solenoidal and torroidal winding wire $10 K, Salary and benefits: Lead Scientist $120 K, Engineer $90 K, Shop Personnel $90 K. Overhead, $40 K for facilities, utilities, travel, conference fees and accounting services. Contingency $30 K.

2. Phase Two.

2.1. Phase Two Technical Objectives.

The first objective of Phase Two is to build and test the storage ring designed as the third objective of Phase One. Successful operation of the storage ring will prove the essential correctness of the ECOFusion design, using components that will later be used in the full ECOFusion prototype. In addition, the small storage ring will demonstrate the technology of beam stacking – proving that a small storage ring can use electron cooling to obtain recirculating currents vastly in excess of the injection current by continuously overlapping and merging the injected ion beam current on top of the beam current that has already been stored during prior injection cycles.

The second objective of Phase Two is to improve the present ECOFusion design. It is known that better operation of the device can be achieved if the design uses a somewhat lower energy and a single beam waist (rather than the two it has now) in the interaction region. The new design should result in a device that uses fewer components, requires less input energy, and yet produces more output energy than the present design.

The third objective of Phase Two is to publish the ECOFusion design in a peer-reviewed journal. Publication will result in comments and feedback from the general scientific community, possibly strengthening and improving the design and allowing for further future improvements.

2.2. Phase Two Cost Proposal.

Phase Two Cost and Duration – $2.5 M, 18 months.

Cost Breakdown - Four dipoles, $120 K, eight solenoids, $180K, six quadrupoles $180 K, beampipe, ceramics and stands $100 K, power supplies and control racks $120K, control system $150K, radiation monitoring equipment $75K, water cooling system $75K, instrumentation and diagnostics $75K. Salary and benefits: Lead Scientist $240 K, two engineers $360K, four technicians $360K. Overhead: $200K for facilities, utilities, travel, conference fees and accounting services. Contingency: $265K.

3. Phase Three.

3.1. Phase Three Technical Objectives.

The first objective of Phase Three is to build a full-scale, 10 kA electron cooler. Construction of the 10 kA cooler is a critical step in the eventual construction of an ECOFusion prototype.

The second objective of Phase Three is to analyze the performance of the ECOFusion cell designed in Phase Two under conditions of deuterium-deuterium operation. It will be useful to do the initial ECOFusion prototype commissioning using deuterium-deuterium rather than deuterium-tritium due to the sensitive nature of using tritium. (Tritium is used in hydrogen bombs, and is itself radioactive. Hence it is a substance that involves political and technical difficulties that do not exist for deuterium.)

The third objective of Phase Three is to begin specification and procurement of components needed for Phase Four construction.

3.2. Phase Three Cost Proposal.

Phase Three Cost and Duration – $1 M, 6 months.

Cost Breakdown - Large cathode, $125 K, large grids, $50 K, collector, $25 K, power supplies and racks, $30 K, beampipe, ceramic and stands $70 K, solenoidal and torroidal wire, $50 K. Salary and benefits: Lead Scientist $80 K, four engineers $240 K, six technicians $180 K. Overhead: $100 K for facilities, utilities, travel, conference fees and accounting services. Contingency: $50 K.

4. Phase Four.

4.1. Phase Four Technical Objectives.

The objective of Phase Four is to build and test a full-scale ECOFusion prototype. Testing will begin with deuterium-deuterium operation, to verify the accuracy of the analysis done in Phase Three. Empirical knowledge gained during the operation will be fed back into the design, and the design improved. Once a satisfactory agreement between operation and design is achieved, the deuterium-tritium design will be used to adjust the equipment for deuterium-tritium operation.

It is expected that deuterium-tritium operation will demonstrate that ECOFusion cells are capable of producing energy, resulting in the many benefits described above in section 1.1.

4.2. Phase Four Cost Proposal.

Phase Four Cost and Duration – $6 M, 21 months.

Cost Breakdown - Three large cathodes, $400 K, large grids, $100 K, three collectors, $75 K, beampipe, ceramic and stands $225 K, solenoidal and torroidal wire, $150 K, two merging and separating dipoles, $100 K, 11 solenoids $220 K, 16 quadrupoles, $480 K, power supplies and racks, $300 K, additional vacuum pumps, $100 K, two deuterium ion sources and injection lines, $150 K, high voltage deck with isolation power supply $850 K. Salary and benefits: Lead Scientist $300 K, six engineers $700 K, six technicians $350 K. Overhead: $300 K for facilities, utilities, travel, conference fees and accounting services. Contingency: $1.2 M.

5. Total Project Time and Budget.

Total time and cost for ECOFusion prototype development: 4.5 years, $10 M.