Direct Electrical Production from LENR

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Abstract *— This paper reviews various approaches to the direct production of electrical power by using excitations from Low Energy Nuclear Reactions (LENR). Some of the methods only provide low voltages, currents and powers. Efforts are underway to understand and improve the outputs of those techniques. One recent report by Egely describes a device that magnifies electrical energy by as much as a factor of 10. That technology requires both independent testing and commercialization.*

1. Introduction

Chemical energy available from foods is necessary for life. Optical and acoustic energy enable our senses of sight and hearing. Electricity is arguably the next most useful form of energy available to humans. Many energy sources cannot produce electricity directly in one step. Fossil fuels are a prime example. They must be burned to first produce thermal energy, which then can be used to generate electricity. Similarly, the potential energy of water is used to induce mechanical motion in turbines, which power generators. And, wind energy likewise produces motions that power generators. However, some other sources of energy do permit direct, that is, one-step production of electricity. The use of sunlight and solar cells is an important example. Using thermoelectric materials to turn any heat, especially heat that would otherwise be wasted, into electricity is another useful technology.

There has long been an interest in direct production of electricity from plasmas. It is possible to separate the positive (ion) and negative (electron) charges in a plasma to produce a voltage. That can be done by passing the plasma through a static magnetic field.[1] The Lorentz force[2] will act in different directions on the positive and negative charges in the plasma, leading to charge separation and voltage development. Since a plasma is a conductive medium, moving a plasma through a magnetic field will generate a voltage along the length of the plasma. The situation is like the motion of a wire conductor in a magnetic field within an electrical generator.[3] Similarly, producing a moving magnetic field in the presence of a plasma will lead to electrical generation. However they are used to produce electricity, a plasma system is commonly called a magnetohydrodynamic (MHD) generator.

MHD plays a central role in the confinement and control of hot plasmas in fusion research systems. Most hot fusion plasmas are used to produce thermal energy. However, in some cases, hot fusion is being developed to directly generate electricity. The company Helion is seeking to use aneutronic fusion of deuterons and He-3 to generate electrical pulses.[4] Information on Helion and its funding is available.[5]

Most of the attention to energy generation with LENR has been devoted to production of heat. If the temperatures are high enough, greater than 300 to 400°C, then it is possible to generate electricity, albeit with the normal inefficiencies due to thermal losses and Carnot limitations. However, for several years, there has been some attention to direct electrical production with LENR. That approach does not require the inefficient intermediate step of producing heat, and then converting some of the thermal energy to electrical energy. A few approaches to direct conversion of LENR energy to voltages have appeared in the literature. In one, the charge separation needed to generate a voltage is achieved using semiconductors with junctions that provide charge separation to the two electrodes. In another, there are other materials between the electrodes. Two types of direct conversion LENR devices, which have gaps without materials between them, have been demonstrated. In one, there is gas in the gap and in the other an intermediate plasma is produced.

If direct conversion of LENR energy to electrical energy can be made a reliable and efficient process, it might be less complex and cheaper than the production of heat and the use of generators. Interest in direct electron production from LENR has grown rapidly in recent years, and is reviewed in this paper. We first survey some old papers that are relevant to the topic. Then, we review systems using solid semiconductors and other materials between the output electrodes. Next, we summarize the systems with gaps without solids connecting the electrodes. There are different gases or plasmas at various pressures in the gaps.

The techniques reviewed in the rest of this paper involve different types of stimuli to produce output voltages, possibly or certainly due to nuclear reactions. In some cases, there is no input, so that the output voltages are spontaneous. In other cases, there is electrical input, so that the device acts as an electrical power amplifier. For one of the cases, the input electrical power is first converted to another type of energy (a plasma), which in turn stimulates an electrical output.

A central issue in all cases is how to produce the charge separations needed to generate voltages. Separating charges is equivalent to giving them energy because of the work that must be done against the electrostatic attraction. Recall that voltages have units of energy per charge. The mechanisms that produce charge separation, which are operable in the various devices, need to be understood. Another common issue with many of the devices is whether the measured voltages are indeed due to nuclear reactions, or can they be explained by chemical reactions. If the output voltages are due to nuclear reactions, what is their relationship to what might be termed "conventional" LENR? And, can the devices reviewed in this paper be used to increase our understanding of any of the diverse LENR experiments, regardless of whether or not they can be made into practical generators?

2. Direct Conversion Systems with Semiconductors

Before reviewing reports on this approach to direct conversion of LENR energy to electricity, we provide the needed background on the operation of semiconductor materials in circuits. As is widely known, semiconductors can be doped with low levels of various atoms to make them behave as they have a surplus or deficiency of bonding electrons. Doped materials that contain atoms with additional electrons (such as boron) are called n-type, since electrons have negative charges. The materials doped with atoms that have fewer bonding electrons than silicon (like aluminum) have "holes" in their electron structure, which act as positive charges, so they are called p-type. When the two types of semiconductors are in contact with each other, a pn junction forms, which has highly desirable behaviors.

In pn junctions, the Fermi level (the chemical energy) is aligned. The effect is like the flat water level in a swimming pool (due to gravitational energy), which is independent of the depth of the pool. Such pn junctions have energy band offsets, which permit the flow of electrons and holes in specific directions. That operation is like what happens within a solar cell. Figure 1 shows the energy bands and levels near an illuminated pn junction.[6] When a photon is absorbed by the p-type semiconductor, an electron is promoted to the conduction band, where it moves within the empty conduction band to a lower energy state in the n-type material. Hence, electrons flow from the n-type material to the attached metal electrode. Conversely, the holes created in the filled valence band move out of the p-type region into the external circuit. The situation is similar if the photon is absorbed in the n-type material. Then, holes move to the p-type material and its electrode. In both cases, charges are separated and a voltage develops across the two electrodes, which can be used to power external devices. In a LENR system, the excitation of electrons is provided by the energy from the nuclear reactions. Hence, in the LENR direct conversion schemes, semiconductors are placed near the LENR-active materials. Coupling of energy from nuclear reactions to the region of the pn junction is a central issue.

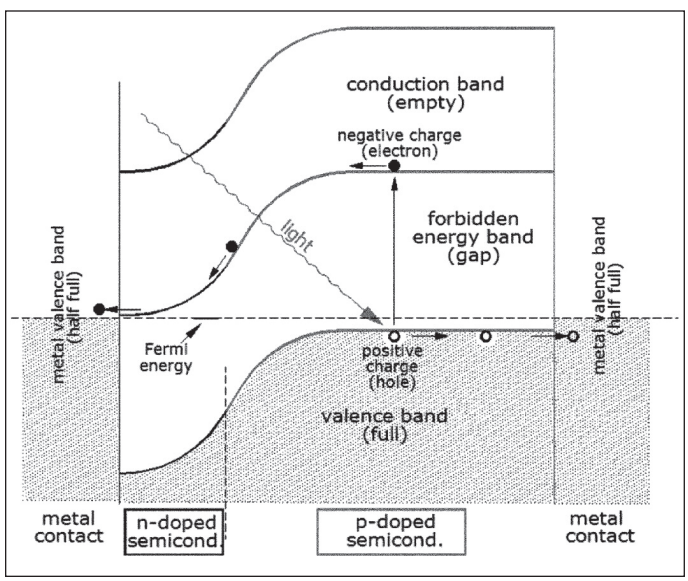


Figure 1. The Fermi level, indicated by the dashed line, is the energy needed to remove an electron from the system, and is the same on both sides of the junction of type n and type p semiconductors.

Figure 2. Three generations of the exterior housing for interior Fusion Diode tubes: Mark III (top), Mark IV (middle) and Mark V (bottom).

■ ***David and Giles Fusion Diodes.*** The first paper on direct electrical generation after the Fleischmann-Pons announcement was presented by David and Giles in 2008.[7] Before reviewing that paper, it is useful to note that David had two patents in the 1990s, which are related to the 2008 paper. In one of them,[8] he patented the design for an electrochemical cell with a platinum anode and heavy water, in which the cathode was innovative. It consisted of a layer of palladium deposited on a silicon substrate. That design produces a high electric field at the metal-semiconductor boundary, possibly able to cause nuclear reactions. In the second patent,[9] David had a mixture of palladium and silicon powders in a cylinder containing tritium gas, with a voltage applied across the powder column. The goal of the device was to cause nuclear reactions involving tritium, thus eliminating its radioactivity.

Returning to the 2008 David and Giles publication, they discussed a device called a Fusion Diode. The abstract of their paper contains useful details:

> Conventionally, the cold fusion reaction produces heat. The authors have sought a different approach, wherein the device has no input energy, relying on the energy produced by cold fusion in the device. The device consists of diodes fabricated as powder, with a large surface junction made up of a semiconductor in contact with palladium charged with deuterium. The apparent fusion reactions take place in the junction between the semiconductor and the palladium powder, which produces an excitation which is transmitted to the electrons. This excitation increases their energy and allows them to cross the bandgap of the semiconductor and pass into the conduction band, as in a photovoltaic cell.

The Fusion Diode was made of intermixed powders of palladium and silicon within a 7 mm diameter glass tube about 60 mm long. The tube had electrodes at both ends and was sealed, with provisions for admitting gas at 1.5 atmospheres into the tube. There was a gradient in the local concentration of the two powders along the length of the glass tubes, one end of which was plugged with glass beads or glass wool, but open to the gas pressure. One to three glass tubes in series were placed within a metal pipe that was sealed and filled with gas. Figure 2 shows different generations of the exterior housing of the Fusion Diodes.

Use of argon gas in Fusion Diodes initially produced a voltage of about 15 mV, which decayed to near zero within a day.

An output voltage near 0.2 V appeared as soon as the metal tube was pressurized with H_2 or D_2 gas. If hydrogen gas was used, voltages up to 0.35 V appeared in about a day. With deuterium gas, the voltage grew to values as high as 0.5 V, again in one day. The time history of the voltages was not monotonic, and some sudden drops or increases in the voltage occurred during the runs. The graphs of voltage vs time in the paper covered about 1.5 days. There is no information in the paper about reproducibility of the voltage histories for H_2 or D_2 gas from run to run with the same or different devices.

David and Giles wrote that the use of powders "forms a zone of contact (junction) between the semiconductor and palladium. This zone of contact generates a very large contact surface. Importantly it will be noticed that not only a voltage appears, but that this voltage is concentrated in a thin zone, the junction zone. If the junction thickness is 0.5 micrometer, and the voltage 0.5 volt, the field equals one million volts per meter. We propose that in this field of one million volts per meter, the deuterium fusion reaction occurs." They also stated: "Connected to a resistor of the same range than the internal resistance of the diode (some hundreds of kilo ohms), we have recorded a power in the microwatt range." They made an interesting comparison between their Fusion Diode and the nuclear fission pile of Fermi and his team in Chicago in 1942: "The Fusion Diode has 1g of palladium, and had an electrical power in the range of the microwatt, giving a power/mass ratio of 10^{-6} W/g. The Chicago-Pile 1 had a power to weight ratio of 0.25×10^{-6} W/g." The resistance of the load for measurement of the power from the Fusion Diode was not stated. It might have been in the mega-ohm range, a common value for the input of a voltmeter.

In another paper a year later,[10] the two authors stated that voltages of "over 1 V" could be produced by Fusion Diodes. In that paper, they expressed the opinion that the voltages produced with hydrogen gas were due to the small amount of deuterium in the H_2. They raised the question of the source of the voltages they measured. Were they due to chemical or nuclear effects? That question apparently remains open. In the second paper, the authors wrote of diurnal variations of the temperature in the laboratory. However, the time scale on their graph, which was also in their first paper, is not consistent with such variations. The schematic diagram of the Fusion Diode in the 2009 paper was essentially identical to the drawing of the device in the 1996 patent.

The third paper[11] on Fusion Diodes by David and Giles was given in 2011. That paper described efforts by the authors to measure the output of LENR by using calorimetry. They made the point that electrical measurements are much easier than calorimetry, one of the advantages of direct electrical production. They reported that "After some weeks, the voltage drops. We can explain this decay in the energy production of the diode by two hypotheses: Leak of the deuterium out of the container or end of an electrochemical reaction by shortage of adsorbed oxygen." The 2011 paper contained a statement about future improvements in Fusion Diodes: "The authors are planning to build a new type of fusion diode: instead of using a powder mixture, we plan to use discs cut from thin sheets of copper. One side of these discs will be covered with palladium by vacuum metallization, and the other side will be covered with an organic semiconductor. By stacking several hundred of these disks we think it will be possible to produce far higher voltages." Devices with discs instead of powders were later fabricated and tested. The 2011 paper also contained a discussion of the authors' ideas on the mechanisms active in their devices.

The next paper in the series by David was presented in 2015 at a workshop in Toulouse.[12] The abstract states, in part: "The author proposes new experiments intended to study hydrogen isotopes in metal alloys and shows some experimental results in the field of LENR." It refers to the Fusion Diode as the "Clarendon Effect" for a famous laboratory in the U.K.[13] The paper is essentially a review of experiments in the field. It does not contain new experimental results because the Fusion Diode is noted as one of several devices that exhibit LENR.

In a 2018 paper presented at ICCF21,[14] David and Giles stated that there are many hydrogen-rich materials, which should be tested for LENR activity. That remains the case, and is a promising arena for further LENR research. The main thrust of the 2018 paper was on alternatives to calorimetry for determination of the occurrence of LENR. Fusion Diodes were among the approaches discussed. One of the graphics in the presentation showed devices with palladium-covered silicon as cathodes, the method of the 1991 patent by David. Other graphics in the presentation showed many components and versions of the Fusion Diode. A paper based on that presentation was published in 2020.[15]

In 2021, David presented two papers entitled "Direct Conversion: Replications," one a poster at ICCF23 in China[16] and the second at the 14th International Workshop on Anomalies in Hydrogen Loaded Metals in Italy.[17] The poster contains a review of five generations of the Fusion Diode, Mark I through Mark V. It included measurements of the output of the Mark IV Fusion Diode performed by Biberian, shown in Figure 3. The diode was in a sealed container pressurized with 2 atmospheres of deuterium gas. The vertical axis is voltage and the horizontal axis is time, with each vertical line marking one day. It is seen that the voltage starts at

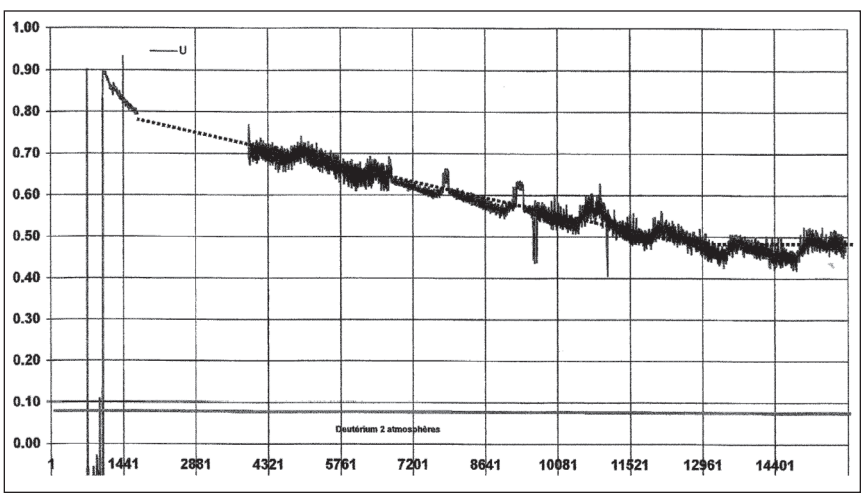


Figure 3. Voltage-time history for a Mark IV Fusion Diode in a deuterium atmosphere, as made by David and measured by Biberian. The sloping and horizontal dotted lines are guides to show trends, and not fits to the data.

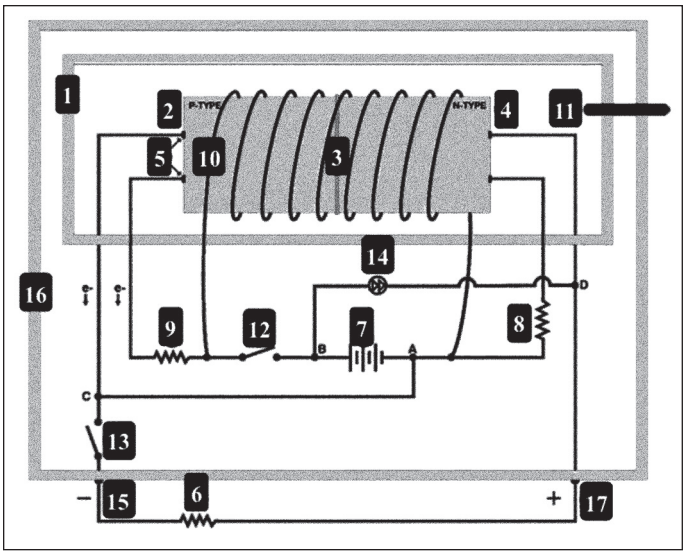


Figure 4. Schematic of a conceptual system designed by Moon for LENR production of electricity.

0.9 V, declines rapidly for about a day, and then decreases rather steadily over about eight days, and finally seems to stabilize at about 0.48 V. Some peaks and variations occur at daily intervals. They might be temperature effects.

The 2021 presentation in Italy by David consists of 70 graphics that review his work with Giles, and also discusses work by others. The latter will be noted below. That presentation included new material on the Mark VI Fusion Diode. It consists of layers of circular disks stacked in a tube and pressed together. David wrote, "An aluminum container of the same model as the Mark V is used, but the powders are replaced by an alternation of palladium foils with an organic semiconductor layer and aluminum foils." Data from the new design has yet to be presented.

A paper entitled "Solid-State Fusion Diodes: Preliminary Results" was presented at ICCF24 by Brandenburg and David.[18] The lead author is the Astronautics Division Chief Scientist at Kepler Aerospace in Texas.[19] That company is working on both hot and cold fusion for propulsion of space vehicles. The ICCF24 paper included material on their motivations, some of their theoretical ideas and a review of work by David on Fusion Diodes.

The question raised by David and Giles on the origin of their measured voltage, either nuclear or chemical, can be addressed. They wrote of performing long-term experiments, which would exhaust chemical sources, to prove the nuclear nature. However, ensuring that the devices do not leak deuterium is a major challenge. The possibility of sealing Fusion Diodes in glass envelopes to prevent the escape of hydrogen was noted. To quote David: "In order to determine whether the spontaneous polarization was due to nuclear reactions, or to an electrochemical artefact, we had glass tubes made in order to flame seal the Mark IV and Mark V diodes under a hydrogen atmosphere. Thus it will be possible to maintain the deuterium pressure, as well as the tension, for several months, or even years, and to exclude a chemical reaction." Connection of the experimental containers to pressure bottles containing H_2 or D_2 is also possible.

Besides the origin of the measured voltages in Fusion Diodes, their time variations, temperature sensitivity and the overall durability of the output power remain questions to be answered. It appears that no one has built other Fusion Diodes of similar design to those of David and Giles. It seems good to follow up on the work of David and Giles by using alternating layers of palladium and semiconductors, in order to have a more controllable geometry. That is being pursued by Brandenburg and David by sputtering palladium onto silicon wafers on one side and gold on the other side. Small diameter thin silicon wafers are commercially available.[20] In a related, but different approach, palladium could be co-deposited electrochemically with deuterium on such wafers. The deposit would be an irregular thin layer of fine palladium particles. Pressing such coated wafers together would leave pores for deuterium gas to permeate the structure. It is possible that such structures would prove to be stable, and electrically active for relatively long times. It would also be possible to separate the wafers in the stacks by use of spacers. Doing that would make the Fusion Diode structure somewhat like those of the Lattice Energy Converter to be reviewed below.

■ ***Moon Nucleovoltaic Cell Concept.*** Another idea for direct electron production by LENR, also using semiconductors, was introduced by Moon at ICCF11 in 2004.[21] He called it the Nucleovoltaic Cell. It appears that the system was never built and tested. However, we provide a brief synopsis of the system and its potential operation. Figure 4 is a diagram of the components of the system. It consists of an inner pressure vessel (1) with a gas inlet (11), and an outer housing (16). The central component consists of two semiconductors, one p-type (2) and the other n-type (4), which are joined at a pn junction that is indicated by (3).

It appears that the labelling of the two sides of the semiconductor in Moon's diagram in Figure 4 is opposite to what would be expected. However, we can continue to examine Moon's concept despite the labelling problem. His text states: "The working element is an N-type semiconductor which has been coated with a thin film (a few hundred angstroms) of hydrogen-active metal, for example palladium." The central point is that LENR occurring in the thin palladium film, due to absorption of deuterons from the atmosphere in the pressure chamber, will excite electrons across the band gap, as in a solar cell, and lead to carrier motion, which is the desired electrical current. That current can be used externally, if the outside switch (13) is closed, to deliver current to the external load (6) through the terminals (15, 17). Alternatively, the current can be used internally to recharge the battery (7) through Points C and A, the current-limiting resistor (9) and the diode (14).

The use of the Moon system occurs in two stages, startup and steady operation. For startup, the internal switch (12) is closed, permitting current to flow from the battery through the coil (10) to resistively heat the palladium-covered surfaces of the semiconductors. That will presumably increase diffusion into the palladium and lead to LENR. Once LENR are occurring and exciting electrons within the semiconductors, switch (12) can be opened to stop power to the coil and its heating. Electron current then flows internally from terminals (5) through Points C and A, either to recharge the battery or return through the current limiting resistor (8) to the semiconductor.

There is nothing in Moon's paper on the size scale of the

components in his concept. It is possible that the system could be reduced to a very small scale, even on a chip, except for the battery and pressure vessel. Even if the system were not small in area, making the two doped semiconductors (and their junction) thin could ensure that energetic particles from the LENR source, the deuterium loaded palladium, could reach all the volume of the semiconductors. Building and testing a system of any size based on this concept might be a good Ph.D. research project. The two most basic questions are: (a) would it work at all, and (b) what would be the output characteristics of voltage, current and power? The longevity of such devices would also be of interest.

3. Other Solid-State Direct Conversion Systems

Two very different and significant groups have reported voltage generation from experiments involving hydrogen isotopes, which may be due to LENR. Swartz and his colleagues have had a long interest in direct electrical generation. They recently produced a new paper in which ultrasound is shown to produce voltages in devices loaded with dry nanoparticles. The other source of information is a company in Florida, BioSearch, where a team has been working on direct electrical generation for over a decade. The approaches and results reported by the two sources are reviewed in the following paragraphs.

■ ***Swartz NANOR™ Experiments.*** He has reported on many innovative experiments with both[22] liquid electrochemical systems and solid-state devices, which he calls NANORs™. The latter are two-terminal devices, somewhat like, but smaller than the Fusion Diodes of David and Giles. Most importantly, they are not filled with semiconductor materials. Rather, they are small tubes filled with nano-scale metallic particles of Pd, Ni and their alloys that are separately encapsulated in insulating coatings of zirconium oxide. Figure 5 is a photo[23] of two of the devices, which are the sections near the dashed lines between the insulated lead wires.

Swartz and his colleagues have worked on NANORs™ for over a decade, and have published about a dozen papers on their work with the devices. The production, composition and geometry of NANORs was described in one of Swartz's early papers.[24] The production process involves melting and rapidly quenching of alloys containing Pd, Ni and Zr. Then, to quote their paper:

> Upon heating in air, the zirconium metal oxidizes into the ZrO_2 (zirconia) matrix which surrounds, encapsulates, and separates the NiPd alloy into 7-10 nm sized ferromagnetic nanostructured islands located and dispersed within the electrically-insulating zirconia dielectric…The NANOR™-type of LANR devices contain active nanostructured material in the core, which is ZrO_2-PdNiD, ZrO_2-Pd, ZrO_2-NiD, ZrO_2-NiH, ZrO_2-PdNiDAg, and ZrO_2 PdD, with the atomic ratios being usually in the range of Zr (~60-70%), Ni (0-30%), and Pd (0-30%) by weight, with the weights being before the oxidation step, and several later additional preparation steps. The additional D_2 and H_2 yield loadings (ratio to Pd) of up to more than 130% D/Pd. For simplicity, all of these nanostructured materials in the core, in their range of deuterations, will henceforth simply be referred to as ZrO_2-PdD, ZrO_2-NiHD and ZrO_2-PdNiD.

Materials such as Swartz uses in NANOR™ devices were developed and reported in 2002 by Arata's group.[25] They have been used in many hot gas experiments in Japan. It is interesting that the hydrogen isotopes used by the Japanese and Swartz penetrate the ZrO_2 coatings on the metals and alloys of the nano-particles with both heat generation and charge separation resulting.

Most of the work with NANORs™ reported by Swartz has resulted in heat production. Large power and energy gains have been measured from those experiments.[26] Very recently, Swartz returned to measuring direct electrical production using his NANORs™. His 2022 preprint[27] is entitled "Direct Electricity Production from NANOR®-type ZrO_2-PdNiD Components Using Ultrasound." In the preprint, he cited two presentations from 2010 and 2011[28] on direct electricity production stimulated by ultrasound. Both were co-authored with Entenmann.

In the new paper, Swartz and Verner present data on the relative electrical (voltage) output when a ZrO_2-PdNiD NANOR™ device was exposed to ultrasound and magnetic fields, sometimes separately and sometimes simultaneously. Figure 6 contains the data. The magnetic field

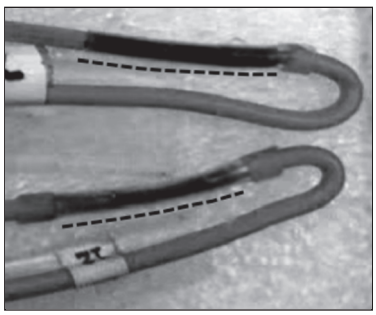


Figure 5. Two NANOR™ devices.

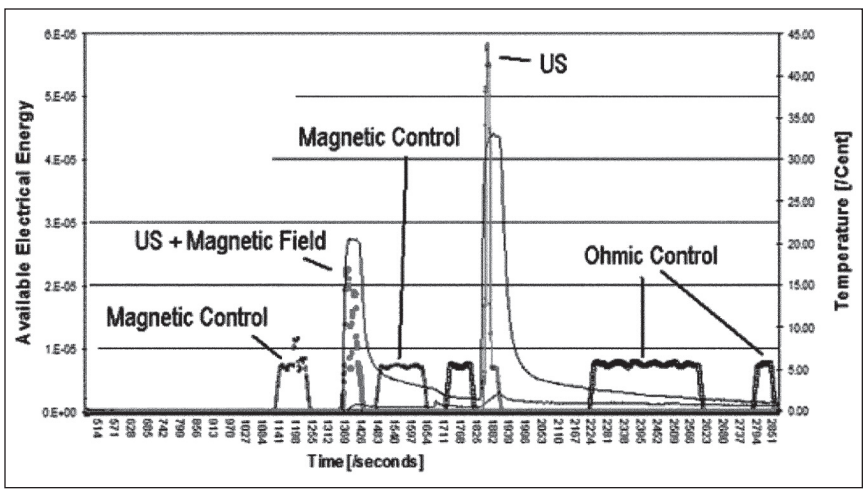


Figure 6. Relative output electrical voltage (left scale) for excitation of a NANOR™ device by magnetic fields alone (Magnetic Control), ultrasound alone (US) or both (US + Magnetic Field), along with heating introduced by resistive controls (Ohmic Control). The data with magnetic fields and Ohmic controls sets the floor for the voltage output. Voltages for ultrasound stimulation are well above that floor. The two continuous curves are temperature measurements (right scale) from two sensors with different responsivity. Temperatures measured with the better sensor show that ultrasound, whether with a magnetic field (US + Magnetic Field) or alone (US), also results in large temperature increases.

alone did not produce a voltage increase, but the ultrasound with or without the magnetic field was effective. It produced voltages as high as a factor of over 50 greater than the baseline (floor) with no stimulation. The electrical output, while measurable with a good instrument, was small. The preprint states "the efficiency of energy conversion is small [10^{-13} - 10^{-14} of the transiting ultrasonic energy] at this time." Current and power output values for various loads, and hence the overall efficiency, were not in the preprint.

The new work by Swartz, like his measurements of LENR by Raman spectroscopy,[29] might offer a way to detect such nuclear reactions at levels much lower than the best calorimeters. Whether or not it will prove to be scalable to practically useful levels remains to be determined. However, it is already an interesting scientific challenge. How can ultrasound stimulate charge separation and voltage production in the complex nano-materials, much of which is the insulator ZrO_2? The wavelength of ultrasound in solids is roughly 1 mm. While that seems small, it is large compared to the size of the nano-particles.

■ ***BioSearch Experiments.*** A company named BioSearch in Florida, funded by Entenmann, has also been working on direct production of electricity from LENR for about a decade. Unlike the work by Swartz and his colleagues, their research has not been presented at conferences. The company obtained a U.S. patent in 2016. However, the work of BioSearch was little known until recently. In October of 2021, *Infinite Energy* magazine distributed a 23-page report of the activities and results obtained by BioSearch. The title of the report is shown in Figure 7. Curiously, the report did not list any authors, but thanked "numerous scientists who have consulted with BioSearch on experiments."

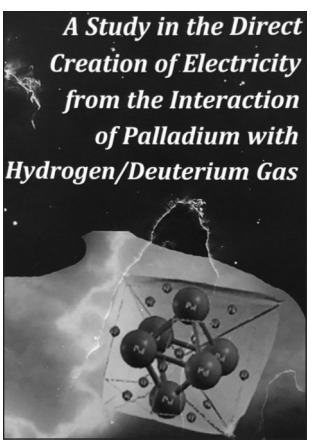


Figure 7. Part of the cover of the BioSearch report as published by the New Energy Foundation in 2021.

Summaries of the patent and report are in the following paragraphs. Both describe many alternatives of cells, conceived in the patent, or designed, fabricated and tested in the reported work, both for direct production of electricity from diverse materials in atmospheres of hydrogen or deuterium gas.

The BioSearch 2016 patent entitled Electric Energy Cell (U.S. 9,472,812 B2) is interesting both scientifically and practically. It includes diagrams of a dozen different configurations of metallic, insulating and semiconducting materials. In all of them, the anode material is capable of "splitting" H_2 or D_2 gas. Six categories of anode materials are listed, including Halide Salts, Alloys, Oxides, Metal Powders, TDAS and Other, which include materials of various compositions and preparation techniques. TDAS stands for Thermally Decomposable Anode Salts, the products of which produce the desired decomposition of the hydrogen isotope molecules. The variety of alternative embodiments in the BioSearch patent is illustrated in Figure 8 (2C from the patent), which is not a complete listing of the presented alternatives in the patent. The symbols in Figure 8 stand for the following: EC = Electrical Conductor, AN = Anode, CAT = Cathode, SC = Semiconductor, I = Insulator and Alt I = Alternative Insulator. The presence of insulators in or near the centers of the alternative designs in Figure 8 is noteworthy.

Parts of the BioSearch patent read much like a research report. It includes the description of two stages: "Stage 1 directed to an LENR-focused field of electrical work; and Stage 2, a system that is more similar to that of a fuel cell." Later, the patent contains a very interesting statement: "Initially, it was assumed that cells of this disclosure would generate electrical voltage as a result of an LENR reaction. This theory was further supported when the addition of the lithium and boron component helped to stabilize the cell. As the testing progressed, however, the results directed operating assumptions towards a new type of fuel cell—a fuel cell absent a constant supply of fuel and devoid of a known ion transport mechanism." That dilemma, nuclear or chemical, is currently in play regarding the Lattice Energy Converter to be described below in Section 4 of this paper.

Further, the patent states, "Stage 1 included testing over 1,300 cells. Early cells exhibited fluctuations in voltage and reversals of polarity completely at random. Semiconductors were added to the configuration in attempts to direct the flow of electrons in one direction and to stabilize voltage fluctuations. The semiconductors did not, however, solve either the voltage fluctuation or reversals of polarity." The patent lists 25 "examples" of devices constructed of various materials by diverse techniques.

Data on the performance of some of the many BioSearch cells in the text and figures of their patent are noteworthy. In particular, this statement deserves attention: "These cells have maintained 500 mV-1000 mV for over 15 months. The cells were refilled with deuterium gas to <50 psig 3.5 months into the cycle. For over 12 months the cells have produced over 500 m V, but very low current." There are 35 figures in the patent, the last 15 of which are time histories over hours or days of the output voltage or current of many cells. The data in most of the graphs are not constant, and some are erratic. In general, the voltages are well under 1 volt, and the currents are on the scale of microamps or nanoamps. The resistance of a few devices is given, and is seen to be erratic.

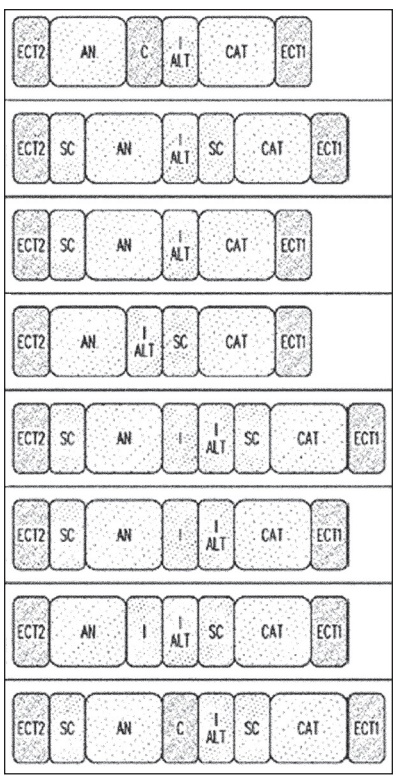


Figure 8. Various embodiments in the BioSearch patent.

It seems that the BioSearch patent might teach, as is required for a patent. However, figuring out what to do

from the many configurations, materials and processes described in the patent would be challenging. Someday, it might be possible to understand the many results documented in the patent. However, that is far from certain.

Turning now to the BioSearch report, we find a situation somewhat like that in the patent. The report describes the make-up of several types of experimental cells, and the types of measurements that were made with techniques other than electrical measurements. In particular, two means of measuring emitted radiation were employed. One was a Geiger counter. In one experiment, "radiation counts were slightly above ambient levels." The other radiation detection system was a cloud chamber. Materials that had been part of experiments with deuterium gas were introduced into the chamber. The report contains the statement, "In the cloud chamber, particles were occasionally observed leaving the surface of the palladium or nickel." In short, BioSearch did not measure significant radiation from their experimental devices or materials. Both permanent magnet and lasers were used in some experiments. However, no effects due to their magnetic fields or electromagnetic fields were observed.

Most of the BioSearch devices described in the report consisted of solid materials between the terminals. Many of the systems were made of discs of materials, which were coated with different substances, and then stacked between the two output terminals. The discs were 2 inches in diameter in many of the experiments. The stacks of discs generally varied between five to ten single-coated or multiple layer cells. Most of the cells in the BioSearch work were dry. However, they did some experiments in which cloths wetted with light or heavy water were introduced into the stacks of solid disks. They did other experiments in which solar cell or thermoelectric materials were exposed to deuterium gas. The wet cells, and the cells with solar cell or thermoelectric materials, did not give significant results.

The voltage time histories and cumulative charges produced as a function of time for diverse devices were measured by BioSearch, and are shown in their report. There is a total of 28 data histories in the report. One experiment pressurized with D_2 gave an initial output near 4 V, which declined unsteadily to about 2 V over 15 days, and stabilized at 1.8 V for five days. That time history is shown in Figure 9. No reason was given for the termination of the experiment. The cell, which produced the voltages shown in Figure 9, consisted of a stack of eight individual cells consisting of six materials: copper powder, n-type bismuth telluride, LiFB, palladium nitride baked onto magnetite, p-type bismuth telluride and copper powder. The reasons behind those choices of materials, which were sealed into a glass tube, were not provided. Nor were the thicknesses, particle sizes or pressure in the stack provided. Reasons for the voltage variations are apparently unknown, a common situation for LENR experiments.

Some of the time histories of voltages given in the BioSearch report extend to a few weeks, the longest being almost 40 days. Late in the report, the authors described cells that contained layers of silver oxide and palladium on carbon, which were separated from each other by glass wool. They were in plastic tubes within glass tubes that were pressurized with hydrogen. Three such cells were connected in series, and produced an open circuit voltage of 3 V. They were then used to power 25 red LEDs. The report discusses the fractional reduction of the AgO, which was up to 43%. That implies that the system was operating chemically, at least partially and maybe entirely.

David provided a statement about the performance of one BioSearch experiment on the LENR-Forum[30]: "a BioSearch cell composed of 10 fusion diodes in the same tube has produced a voltage of 10 volts in open circuit, and a current of 262 microwatts at 3.7 volts." He worked with BioSearch on two occasions to transfer to them his Fusion Diode technology.

At the end of the report, the authors listed several possible activities in a short section entitled "Next Steps." Most of the suggested experiments were parametric variations such as varying the gas pressure, and the use of other materials as anodes. Even without that list, the BioSearch report obviously invites more experiments to replicate their findings, and to demonstrate both the longevity of the results and their scaling to useful levels. Given the nature of the BioSearch experiments with both palladium and hydrogen isotopes, it is possible that the observed effects were due to LENR. However, additional measurements are needed to connect what was done and found by BioSearch to other LENR experiments involving electrochemical, hot gas and plasma loading. It is possible that the BioSearch results will contribute to the understanding of LENR mechanisms. It seems less likely that they will lead to durable LENR generators, which have high enough output power, adequate longevity and needed control to be widely useful.

4. Direct Conversion Systems with Gaps and Gases

Energetic radiations from LENR interact with semiconductors and other materials in the devices described above. The benefits of those interactions are charge separation and the development of voltages. The problem with those interactions is that they can also produce radiation damage, especially in semiconductors, and possibly also in the other materials central to device operation. For that and other reasons, there is interest in direct conversion LENR devices that do not involve materials that might degrade due to radiation damage. Such devices might have gas-filled gaps at various pressures between their output electrodes. Reports on such devices are reviewed in the following paragraphs. They include work by Gordon and Whitehouse on the Lattice Energy Converter (LEC), reports by multiple scientists on replication of the LEC, discussions on how the LECs operate and potential future experiments with LEC and similar devices. A presentation by

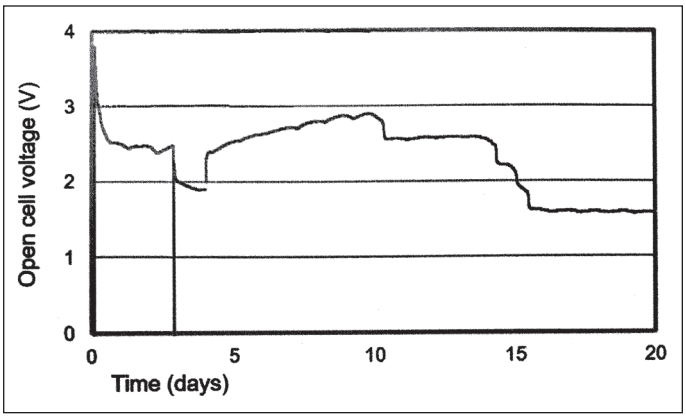


Figure 9. Variation of the output voltage over 20 days for one of the BioSearch experiments.

Egely on a very different sort of electrical power amplifier, which has intermittent plasmas in the gap between electrodes, is reviewed late in the next section.

■ ***Gordon and Whitehouse LEC Devices.*** These two scientists designed and conducted an experiment intended to be like electrochemical LENR experiments, but with a gaseous medium rather than a normal liquid electrolyte between the electrodes. Figure 10 is a schematic of their setup for the experiment, as presented at two meetings and published in their first paper.[31] In their description of the experiment, the authors wrote: "In experiments to see if 6 μCi of Am-241 was sufficient to ionize a gas to load hydrogen into a Pd lattice and retain it using fugacity, we realized that the current conducting in the cell was several orders of magnitude greater than expected from the Am-241. No conduction was observed when the Pd-H electrode was removed leaving only the 6 μCi Am-241 sources, *i.e.*, it was below the sensitivity of our instrumentation. When the Am-241 was removed, the cell conducted with only the Pd-H." They concluded that the Pd-H layer on the inner electrode was ionizing the gas.

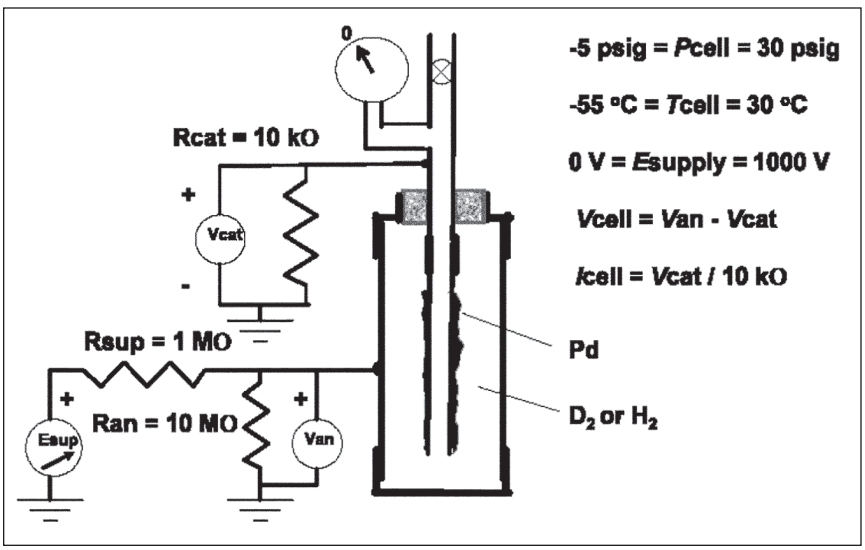


Figure 10. Schematic of the arrangement used by Gordon and Whitehouse in an attempted high temperature gas electrolysis experiment.

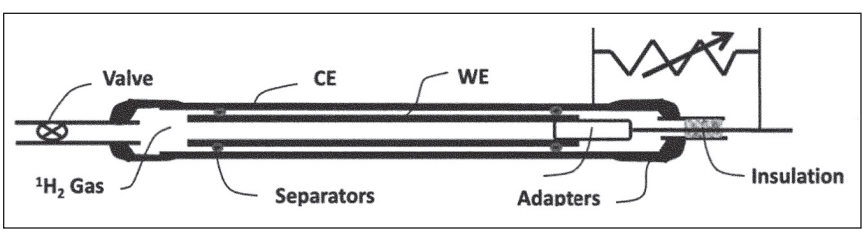


Figure 11. Schematic diagram of a cylindrical Lattice Energy Converter. The output voltage is measured across the variable resistor.

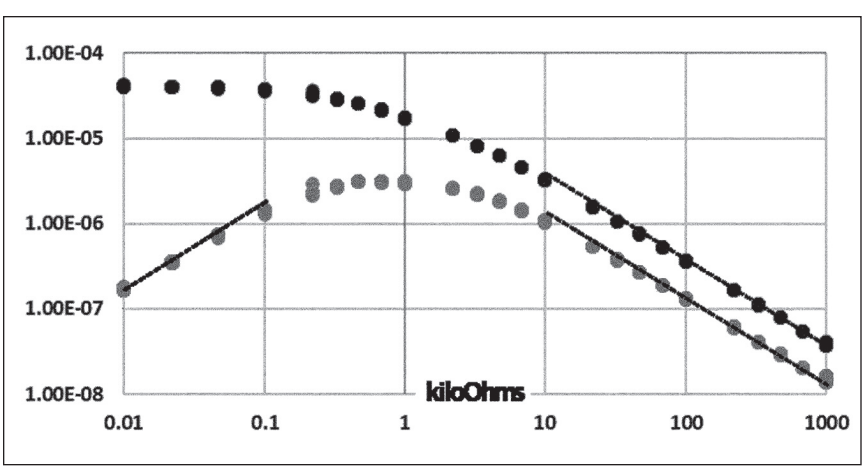


Figure 12. Variations of the output current of a LEC device (top data), and the associated electrical power (bottom data), as a function of the load resistance. The device was made and measured by Gordon and Whitehouse. The dotted line on the left shows that the power increases linearly with the load resistance for low load values. The dotted lines on the right show that the current and power decrease inversely with the load resistance for high load values.

Based on their discovery, Gordon and Whitehouse developed a cylindrical direct electrical output device, which they call the LEC, short for Lattice Energy Converter.[32] It consists of an inner Working Electrode (WE), which is coated by electro-deposition with various metals, such as palladium or iron, in solutions of light or heavy water. The co-axial outer Counter Electrode (CE) is made of various metals. The two electrodes are insulated from each other, and made co-axial using separators. Figure 11 is a schematic cross section of a LEC with hydrogen between the electrodes.[33] Interestingly, LECs will produce voltages with a variety of gases between the two electrodes, including air.

The variation of the output voltage and current of LEC devices with the load resistance is interesting. An electrical power source is typically characterized by measuring the open circuit voltage and the short circuit current. In the case of the LEC, the voltage measured through a 10 MΩ load impedance is assumed to be the "open circuit" voltage. The "short circuit" current is taken to be the current that is calculated using Ohm's law when the voltage produced through a load resistor of lower value is at the sensitivity of the instrumentation. The voltage produced by LEC devices increases with resistance for low resistances, and becomes approximately constant at high resistances. Figure 12 is a plot of the current and power that were calculated as a function of load resistance for a LEC made and measured by Gordon and Whitehouse. It is seen that at low resistance values, the current I is about constant, and the power P increases linearly with resistance R since $P = I^2R$. However, at high resistances, given the nearly constant voltage V, the current decreases linearly with the inverse of the resistance $P = V^2/R$. Those measured variations challenge explanations of the fundamental behavior of LEC devices. Specifically, why is the current constant at low load resistances, and why is the voltage nearly constant at high load values? Gordon and Whitehouse addressed those questions in their two *JCMNS* papers.[31,34] They conjectured in their first publication that the constant current behav-

ior at low resistance values is due to diffusion of ions in the gas, which was predicted by Darrow in 1932.[35]

The abstract of the initial published paper by Gordon and Whitehouse, which involved palladium deposition, reads in part:

> Multiple implementations of a Lattice Energy Converter (LEC) have demonstrated the ability to self-initiate and self-sustain the production of a voltage and current over extended periods of time. A LEC converts the internal energy within the lattice of some materials, such as palladium, or of gases occluded within the lattice, such as hydrogen or deuterium, into ionizing radiation and electrical energy. Experiments include tests where the current-voltage (I-V) characteristics of the LEC were measured when an external voltage/current was applied, as well as other I-V tests where the spontaneous LEC voltage was measured as a function of temperature and resistance. LEC voltage and current has been shown to increase with increased temperature.

The second paper by those authors provides additional information on experiments with LEC devices.[34] It dealt with deposition of iron on the Working Electrode. Part of the abstract follows:

> Replicated experimental results and analysis for a LEC wherein a co-deposited palladium-hydrogen working electrode produced spontaneous and sustained electrical energy attributed to ionizing radiation have been previously reported. Herein is reported the use of a working electrode comprised of co-deposited iron-hydrogen from an aqueous solution of $FeCl_2$ which demonstrated similar capabilities to produce spontaneous and sustained electrical energy as well as ionizing radiation.

The second paper provided additional information beyond a presentation at a conference, which is available on YouTube.[33]

In their presentation at ICCF24, Gordon and Whitehouse addressed possible ways to increase the output power of LEC devices.[36] Part of their abstract provides a good summary of the paper:

> While the ability to self-initiate and self-sustain the production of a voltage and current through a load is a significant innovation, the output must be scaled up by 6 orders of magnitude to produce a few watts, and by 9 orders of magnitude to produce a few kilowatts. Five focus areas have been identified to scale up the LEC output including:
>
> 1. Improved metallurgy to increase the production of ionizing radiation;
> 2. Increased gas density (initial pressure) to increase gas ionization;
> 3. Improved LEC cell configurations to increase ion harvesting efficiency;
> 4. Elevated temperatures leading to increase power output;
> 5. Increased electrode surface area.
>
> For each focus area, additional experiments and analysis are required to:
>
> 1. Identify the source and type of radiation from the working electrode;
> 2. Identify the role that the counter electrode may play in ionizing the gas;
> 3. Identify gases and mixtures that optimize the production of ions;
> 4. Analyze the gas ion physics within the cell.
>
> This paper examines each focus area and identifies possible actions to increase LEC power output.

One of the major features of the operation of LEC devices is their output. Besides being temperature sensitive, which will be discussed below, the output of LEC devices can vary erratically. That is not uncommon in LENR experiments, of course, but remains one of the main challenges for making practical LENR generators from LEC devices or other systems. Figure 13 shows the time variation of the output of two LECs made and measured by Gordon and Whitehouse. The record in the top of the figure exhibits data taken at a rate of 512 samples per second. The vertical axis is a measure of the output voltage of the LEC over a period of almost 8 seconds. Looking at the original data, it can be seen that the output of the LEC can vary on a time scale of less than 2 ms.[37] Between the rapid variations, the output still varies and is noisy.

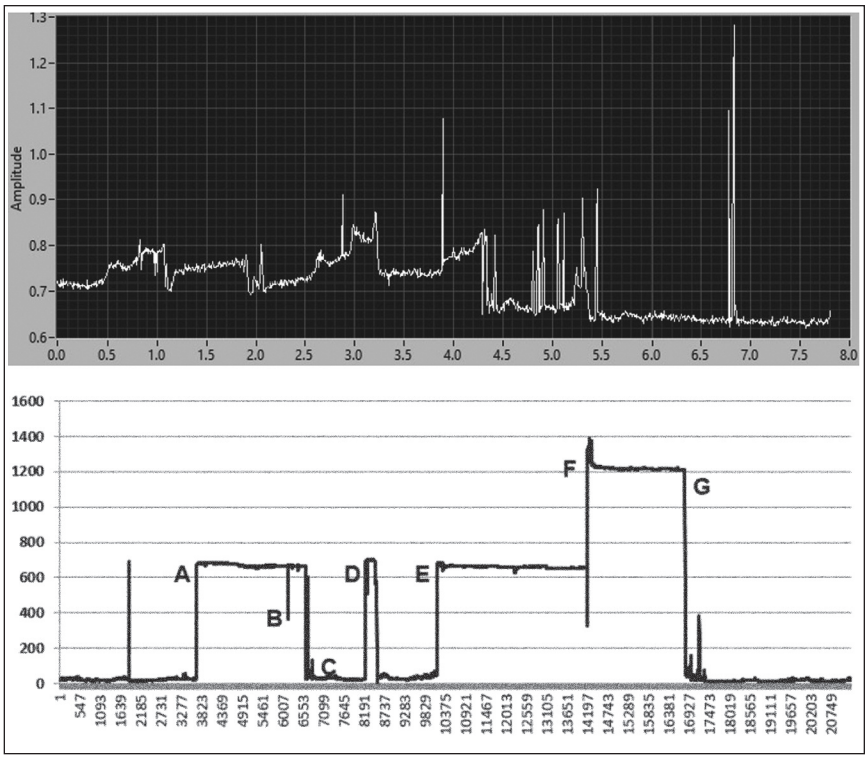


Figure 13. Top: Time history of a LEC output for a time of 8 seconds. Bottom: Variation of a LEC output in mA for a period of 14.5 days. The numbers identify files, each about 61 seconds in duration. See text for details.

Figure 14. Images of LEC devices made by (top to bottom) Gordon and Whitehouse (U.S.), Biberian (France), DiStefano (Italy), Zhang (China) and Erickson (U.S.).

By applying an external electric field of sufficient magnitude between the electrodes, it is possible to sweep out and estimate the number of ions being produced per second before recombination occurs. The data in the bottom of Figure 13 shows that the conduction of current through a LEC is relatively constant due to the fact that the maximum current was limited by a current limiting resistor. This resistance was included as a safety protection, since the potential could be increased to 1000 V. The authors wrote the following: "During periods A, D, and E, the cell was conducting at the maximum allowed by the 1 MΩ current limiting resistor. At F, the current limiting resistor was changed to allow twice the current to flow. At G, the current limiting resistor was further changed to allow more current to flow and the current went up for a few milliseconds and then dropped. At point B, a variable voltage test was conducted." The importance of these data is that the number of ions being produced is greater than the 1.2 mA which the current limiting resistor would allow. The challenge for LEC design improvements is to harvest the ions before they recombine.

It is clear from the work of Gordon and Whitehouse that the coatings of deposited materials on the working electrodes are not uniform in either structure or behavior. They made a LEC with a segmented counter electrode, and the voltages on the two parts were different.[38] That showed the two parts of the working electrode were not equally effective.

In addition to the available papers, presentations and videos on LEC devices, there has been a great deal of email and other discussion of how the LEC devices operate. There are unpublished reports of the polarity of the output voltages reversing during LEC operation. Such reversals are clear challenges to understanding the fundamental mechanisms active to produce LEC voltages.

Both of the Gordon and Whitehouse *JCMNS* papers, and some of their presentations, contain extensive discussion of the dynamics of ionization in the gases between the electrodes. However, what leads to the charge separation, which is necessary to produce the measured voltages, is not yet understood. Here again, the relationship of the mechanisms and properties of LEC devices to earlier LENR reports remains to be discovered. In short, it must be shown that the LEC is not some kind of a chemical battery, and also determined what is the role of nuclear reactions in operation of the LEC. The paragraphs on LEC Mechanisms later in this paper provide more information on the question of why and how LEC devices work. However, we first review the multiple reports of replications of LEC devices and behaviors of LEC devices in other laboratories.

■ ***LEC Replications.*** The development of the LEC led to immediate and widespread interest, given its relative simplicity and performance. A few early experiments succeeded in the production of similar devices and measurement of similar outputs. Three of the replications were done during 2021 in Europe, one was done in China and another occurred in the U.S. They are described in the following paragraphs.

The LEC devices made and measured by Gordon and Whitehouse, and the multiple replicators, have varied widely in composition and geometry. Figure 14 contains images of the devices from Gordon and Whitehouse,[39] Biberian,[40] DiStefano,[41] Zhang[42] and Erickson[43] (the last with a side window for radiation measurements). A double-ended LEC (not shown in Figure 13) was recently described by Gordon and Whitehouse.[38] On the outside, their different appearances seem somewhat like the various generations of Fusion Diodes made by David and Giles in Figure 2. However, the interiors of LECs (gaps filled with gas) are very different from those of the Fusion Diodes (which are filled with solids).

Biberian in France first reported his work with LEC devices at a conference in Italy in 2021.[44] He and Ginestet presented the results of numerous experiments with LECs they built in 2022 at ICCF24.[45] Their initial device is shown in Figure 14. They measured the voltage (up to 330 mV) and power (up to 16 nW) as a function of the load resistance. Then, they built a LEC with a much larger area, and measured as much as 740 mV and 4.5 μW. Measurements with variable temperatures showed that the output declined rapidly above 60°C and reversed sign above 70°C. Yet another LEC design, operated in air, produced voltages as high as 540 mV. Voltage and power with a 1 kΩ load were both erratic in magnitude over time. Temperature variation measurements with a 10 MΩ load gave an Arrhenius behavior below 110°C, and an activation energy of 0.23 eV. The presentation concluded with these statements: "Experiments are reproducible; No effect due to a fixed or variable magnetic field of 0.5 Tesla at up to 6 Hz; and More than 3 orders of magnitude increase in output power by increasing the surface areas of the electrodes."

DiStefano in Italy presented an overview of his research on LEC devices at ICCF24 in 2022.[46] He evidenced concerns about extraneous and small effects. Three reasons for thorough control testing were provided: (a) apparent similarity with conventional technologies, specifically the presence of bimetallic components and temperature gradients, (b) possible electrochemical effects and non-obvious gas phase interactions and reactions, and (c) measurement issues including small signals, instrumental effects and interferences.

DiStefano did tests on LEC devices with no coatings on the working electrode. He reported that the instrumental sensitivity is about 1 μV and less than 1 nA, values much

lower than those from LEC devices. For the main experiments, the working electrode was activated by electrochemical deposition of iron in a light water electrolyte for 8 hours. Counter electrodes of brass and copper gave voltages of -307 and -234 mA, and, currents of -2.4 and -0.69 µA, respectively. Oddly, an aluminum counter electrode produced signals of the opposite polarity, namely 223 mA and 1.5 µA. Spontaneous voltages were measured with loads from 1 to 10 kΩ, and reached -300 mV at the highest loads. Currents were measured for applied voltages from -10 to +10 V. The LEC charged a 100 µF capacitor to 300 mV with a time constant of 15 sec and an internal resistance of 150 kΩ. Radiation from the working electrode was sought with an alpha sensitive tube. Only background levels were measured. DiStefano noted that "The co-deposition process is necessary. If a Fe (or Fe plated) WE is electrolytically loaded with hydrogen, no active behavior is obtained." He provided the following (slightly edited) concluding statements:

- The LEC behavior cannot be explained by conventional effects.
- The repeatability and replicability are very high.
- Electrical measurements suggest a gas ionization occurs inside the devices.
- The energy required to ionize the gases is > 10-20 eV (*i.e.*, not chemical).
- The voltage generation is a second order effect due to the ionization.
- Characterization should be done on the current more than on the voltage.
- The nature of the ionizing radiation needs further investigation.
- Power output is comparable to a commercial beta voltaic battery.
- There are many possible directions to scale up the energy/power output.

Smith and Lilley in the U.K. presented a review of work on LEC devices, and the results of their initial experiments, at the 14th International Workshop on Anomalies in Hydrogen Loaded Metals in Italy in 2021.[47] They reviewed some of the work and results reported by Gordon and Whitehouse, and what was done and found in the early replications by Biberian and DiStefano. Their own experiments used brass plates that were 125 cm^2 in area. The plates were plated with iron over 7 days of electrolysis. Quoting the authors, "The next thing was to stack the WE and CE plates on top of each other in air, not in hydrogen, with the heavily plated side of the WE facing the CE, using 0.9 mm microscope slides as spacers. This gave a peak reading of 350 mV which over the next hour dropped down to 250 mV. Recovery time from a short circuit was not more than 5 seconds." The authors also wrote: "when a WE and CE are separated for some time (say 30 minutes) the output recovers only slowly, taking 20-30 minutes to return to its pre-separation level. It was also found that the closer the WE/CE were, the higher the output, but that even a very thin polythene sheet placed between them instantly reduced the output to zero. The best spacers in terms of performance are both very thin, and very porous, lightweight fly-screen nylon mesh being the most effective separator tested so far. Adding some small lead weights to the top of the stack also improved output and stability by keeping the electrodes flat and thus closer together." The use of flat electrodes for LEC experiments has multiple advantages. The electrode separations can be varied easily with spacers of different thickness. And, the areas of the facing electrodes can be changed rapidly by moving a thin impervious plastic sheet between the electrodes.

Smith presented another paper on his experiments with LEC devices at the 15th International Workshop on Anomalies in Hydrogen Loaded Metals and Clear Hydrogen Metal Energy in Italy in 2022.[48] The abstract of a report is a useful summary of the experiments and results:

> LEC research published suggests that it requires the wet co-deposition of Pd or Fe with a hydrogen isotope onto the surface of a working electrode (WE). When dried and placed in close proximity to but not in contact with a counter-electrode (CE) a very persistent voltage, typically of 200-800 mV, is immediately measureable. The WE and CE may be short circuited many times without reducing voltage output, and output voltage recovery time is rapid, between less than 0.1 sec and 20 seconds depending on the electrode materials chosen and the inter-electrode gap. Voltage is seen when the gas between electrodes is air, hydrogen, or mixed gases and vapours, and is caused by the WE ionising the gas between electrodes, the LEC does not work in a vacuum. Results from the experiments carried out at Net Zero Scientific Ltd. exploring the materials parameter space show that co-deposition is not an absolute requirement and that a broad range of WE materials when loaded electrolytically with hydrogen without co-deposition also show behaviour characteristic of a LEC. These materials include aluminium, nickel, nickel mesh, titanium, ferrocerium, zirconium, samarium, and as powders, terbium, samarium cobalt alloy, and NdFeB alloy.

The report by Smith contains a discussion of potential mechanisms to explain the behavior of LEC devices, as well as a few of the possibilities for errors in LEC measurements. However, the bulk of the paper was on experiments by Smith. He wrote: "The experiments reported here were designed solely to discover if a wider range of anode and cathode materials than has so far been reported on might be used to create LEC type systems…44 tests were carried out using cathode plates 4 x 3 cms approx." Importantly, those tests involved electrolysis in light water and voltage measurements in air. Smith concluded, "Results from various exploratory experiments as well as those reported here have shown that creating a working LEC electrode is not highly dependent on the choice of cathode substrate, anode material, electrolyte, or electrolyte pH, nor is it particularly dependent on the co-deposition of metals onto the WE, or using just one kind of counter electrode or inter-electrode gas or vapour."

Zhang recently posted a well-organized report on the systematic experiments he performed on LEC devices.[49] They are like those of DiStefano, as shown in Figure 14. The work is characterized by having fixed metallic materials for both electrodes, namely titanium, and varying both the electrodeposit and the atmosphere in the LEC devices. Four different electrodeposits and three atmospheres were used, as

Table 1. Conditions and results of LEC experiments by Zhang. Voltage (V), temperature (T) and pressure (P) were measured. The mV values indicate the largest measured voltages.

Electro-Deposit	Atmosphere in the LEC Devices					
	Air		Hydrogen		Deuterium	
	mV		mV		mV	
None	-180	Some T sensitivity	140	V changes sign		
Iron	250	Some V-T relation	95	P follows T	70	P follows T
Nickel			-180	No correlations		
Copper	-280	V is T sensitive	-200	V changes sign		

shown in Table 1. The deposit labelled "None" had electrolysis without any metallic deposit. The thicknesses of the deposited metals were 100 µm for iron and 10 µm for nickel and copper. One of the eight data plots in the report was for 2.5 hours, and the other seven were in the range from half to almost 2 days. Terse comments about the LEC voltages, and the gas temperatures and pressures, which were obtained for the various combinations are provided in Table 1.

Zhang provided the following summary comments (with editorial additions in parentheses):

> • There are many methods to activate the metal surface. In this experiment, we tried to electroplate iron, nickel, copper, and electrolysis.
> • LEC voltage was measured in hydrogen, deuterium, and air.
> • The LEC voltage is unstable (as a function of time).
> • The inner and outer pipes of the reactor are well insulated, and Fermi level, contact electromotive force and thermocouple phenomena are excluded.
> • The experimental repeatability is good (despite erratic time variations).
> • No data higher than background radiation was detected by Geiger counter.

At the end of his report, Zhang provided the following "Additional Thoughts": "LEC experiment has good reproducibility and can be used as a scientific basis. The generation mechanism of LEC voltage is still unclear, and it cannot be explained by known theories at present. Follow-up research needs to do a lot of work, such as X-ray detection, metal surface morphology detection, metal elements detection, isotope detection, gamma ray detection, other rays detection, etc., to find out the mechanism."

Erickson, formerly at Los Alamos National Laboratory, successfully replicated the LEC in his home laboratory.[50] His draft abstract for ICCF24, which was not presented, reads in part:

> In November of 2020, successful replication of a LEC cell was completed with an observed output voltage of over 350 millivolts into a 1 megaohm load in room air. Since that time, over a dozen different LEC cells of different construction have been built and evaluated with observed outputs up to 700 millivolts into a 200-kilohm load resistor. A variety of cells have been run at operating temperatures up to 200 degrees Celsius in vacuum, as well as room air, Argon, and Hydrogen with pressures up to 30 PSIG…More recently, experiments to assess whether ionizing radiation is being generated during the operation of these cells has been explored using a variety of detection methods including a Ludlam "pancake" detector, a doped NaI scintillator, an X-ray sensitive phosphor, a Silicon pin diode and a 3 stage, thermoelectrically cooled cloud chamber.

Erickson has replicated the LEC, but not yet documented what he did and found. He has a cloud chamber in his laboratory, and reported in a 2022 group discussion on the internet that the LEC working electrode produces tracks in the chamber. The nature and energy of the radiation producing the tracks remains to be determined.

In another attempt to measure energetic radiation by this author, an X-ray and gamma-ray spectrometer sequentially viewed four locations on a working electrode plated and provided by Gordon.[51] No significant radiation was detected in the 5 to 160 keV range during any of the hour long runs.

■ ***Standard LEC Design.*** The wide variations in the LEC devices leads to the idea of a standard LEC design. Having and using standard materials and geometries would enable better quantitative comparisons between experiments done in different laboratories. Fortunately, standard fittings, which could be used to make LECs, are readily available from many sources.[52] Part of a LEC based on a standard commercial fitting is shown in Figure 15. The point is that using such fittings, and the LECs that can be made from them, would enable comparisons of similar devices made by different scientists, and also permit better parametric variation experiments. Such experiments might help sort out the various ideas about the mechanisms involved in the operation of LECs.

■ ***LEC Mechanisms.*** As noted above, the separation of charges and resulting production of voltages in devices containing pn junctions in semiconductors is clear. However, the same question of charge separation in LEC devices is still an open issue. There are four main concepts being discussed. The first two are the appearance of charges due to LENR, the kinetic energy of which either causes ionization followed by charge separation, or causes the requisite charge separation

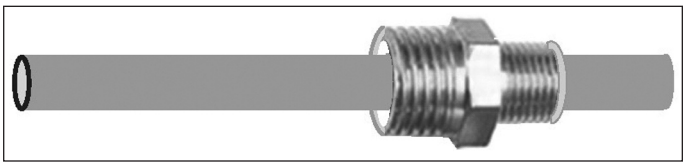


Figure 15. Composite drawing and image of the potential working electrode in a LEC, which could be used to make similar LEC devices for diverse experiments. The grey structure could be a hollow tube of brass or copper, which is electrically insulated from the brass fitting. Both a cartridge heater and thermocouples can be inserted into that tube. The electro-deposit would be made on the outside of that tube. Then, the counter electrode would be emplaced by screwing it onto the fitting. Use of a circular adapter with threads on both its inside and outside would permit use of counter electrodes of different diameters. The counter electrode can be fitted with a sealed cap, which can be mated with a tube and valve to permit evacuation of the inter-electrode space and its filling with a chosen gas at some desired pressure.

when they move from the working electrode to the counter electrode. The third envisions voltages in LEC devices as being from contact potential differences, and similar solid-state phenomena. The fourth mechanism is the diffusion of hydrogen molecular ions (H_2^+) from the working electrode to the counter electrode. All of these ideas will be reviewed in the following paragraphs after we note the numbers of charges involved in LEC measurements.

Current measurements in LEC experiments can be higher than 10 μA. Figure 12 provides one example. Since 1 A is 1 C/sec, and 1 C = 6.24×10^{18} electrons, 10 μA is about 6×10^{13} electrons per second. To understand both conceptually and quantitatively how LEC devices work, it is desirable to be able to relate the measured number of charges per second to the LENR rates that are needed to produce such rates.

Ionization: In their first presentation of the LEC in November of 2020, Gordon and Whitehouse made it clear that they believed their invention worked because of ionization by energetic particles. They were very specific on that point in their next presentation in January of 2021: "The source of the energy to ionize the gas is Pd-H or Pd-D lattice. The specific ionization produced (α, β, Electromagnetic) is not identified. The flux of ionization increases monotonically with increased temperature. The mechanism that produces the ionization is unknown." Some of the replicators of LEC devices and behavior also supported the idea of ionization caused by energetic charges, which were due to LENR, as being the mechanism for how the LECs can provide currents, voltages and electrical power.

The list of quanta that might be energized enough to produce ionization of the gases or solids in LEC devices is not long. Photons capable of ionization fall in the part of the electromagnetic spectrum ranging from the ultraviolet through the X-ray to the gamma-ray regions. Neither hard X-rays nor gamma-rays would be absorbed in the gases or counter electrode surface, even if they were produced in large numbers. UV and soft X-ray radiation, if emitted from the working electrode, could be absorbed in the inter-electrode gas or surface of the counter electrode. However, the separation of the resulting electrons and ions to opposite electrodes would depend on the energy absorbed from the exciting photon, and be critically dependent on the direction of the exiting charges. The main question is what mechanisms cause the positive charges (ions) and the negative charges (electrons and possibly ions) to go to opposite electrodes. There are two mechanisms that determine the motion and direction of the positive and negative ions: (a) ion drift due to electric fields and (b) diffusion due to the spatial gradient of the ion densities. These two mechanisms determine the primary motion of the ions. Thermal agitation and diffusion against the gradient might result in a small number of ions going opposite to the polarity of the electrodes. Overall, the spatially varied and time varying combinations of fields and concentrations, and the relative importance of the active mechanisms, determine the output voltage of LEC devices.

We next consider particles that might produce the conjectured ionization. Neutrons are an unlikely source, because they rarely appear in significant numbers in LENR experiments and are not efficient at producing ionization. Energetic ions can cause ionization, but there is again the question of their production at large rates, many more than billions per second. And, energetic ions should be easy to detect. That leaves electrons or low energy ions as the remaining possibilities. Electrons with sufficient energy can cause the ionization thought by some to be needed for LEC operation. However, both electrons and low energy positive charges would have to be emitted from the WE in significant numbers, and even if that happened, there is the same problem as for photon excitation: Why is there the observed net charge separation? How does it happen?

Kinetic Charge Transfer. It is also possible that fast electrons might simply cross from the working electrode to the counter electrode without causing ionization. Electrons with kinetic energies sufficient to cross between the electrodes cannot be measured in normal electrochemical LENR experiments. Their energies and fluxes (and whatever ionization they might create within a LEC device) are presently unknown. So, the charge separation required for LEC operation might be due to electron momentum. But, again, large numbers of electrons would be required.

Solid-State Effects. In other papers, some of the scientists working to understand the mechanisms active in LEC devices considered the possibilities of various well-known phenomena, such as the Seebeck effect, being the source of the voltages measured from LEC devices. An experiment to test that possibility was done by Gordon and Whitehouse.[38] Their apparatus and the circuit diagram are shown in Figure 16. They wrote: "Outer vessel is a Mason jar that is approx. 3.5 inches in diameter. The working electrode is a 1/8-inch pipe nipple that is co-deposited with Pd-H. Alternating fin electrodes approx. 2 cm by 8 cm are positioned radially around the WE. If the gas is ionized by energetic particles emitted from the WE, this design places the counter electrodes in the region where the Bragg curve predicts the maximum ionization occurs. If the WE is emitting gamma radiation, this design places the CE where the gamma radiation could impact the CE and produce photoelectrons to ionize the gas. The cell is filled with hydrogen gas at approximately ambient pressure." Two voltages were measured as a function of time. The copper-to-zinc voltage (through 10 MΩ) started at 110 mV, rose to 225 mV and asymptoted 170 mV. The copper-to-palladium voltage (through 5 MΩ) started at-50 mV, declined to -110 mA and asymptoted -80 mV. The results of the experiment did not conclusively show the importance of the work function of the electrodes. Further, there is a fundamental

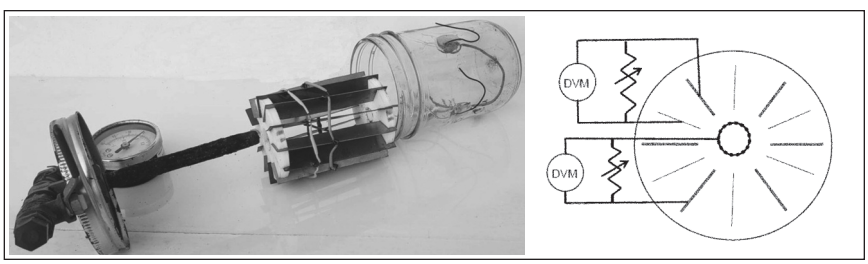


Figure 16. Apparatus designed to show the influence of different work functions from different metals. The working electrode is the black rod in the image, which is indicated by the beaded circle in the circuit diagram.

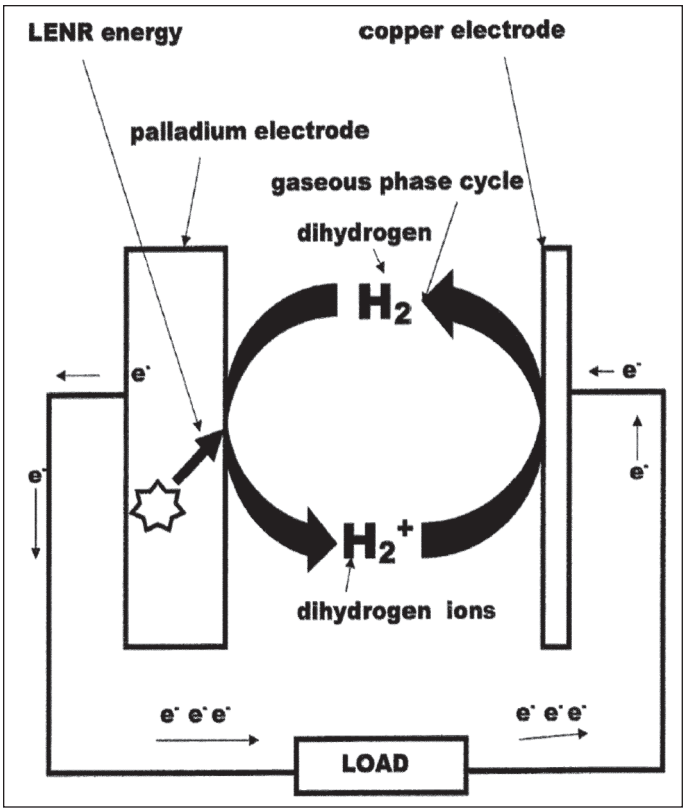


Figure 17. Schematic of the operation of the H_2^+ ion diffusion mechanism presented by David.

problem with the issue of work functions. For them to influence the output voltages of a LEC would require electrical contact between unlike metals. Again, we note Zhang's conclusion: "The inner and outer pipes of the reactor are well insulated, and Fermi level, contact electromotive force and thermocouple phenomena are excluded."

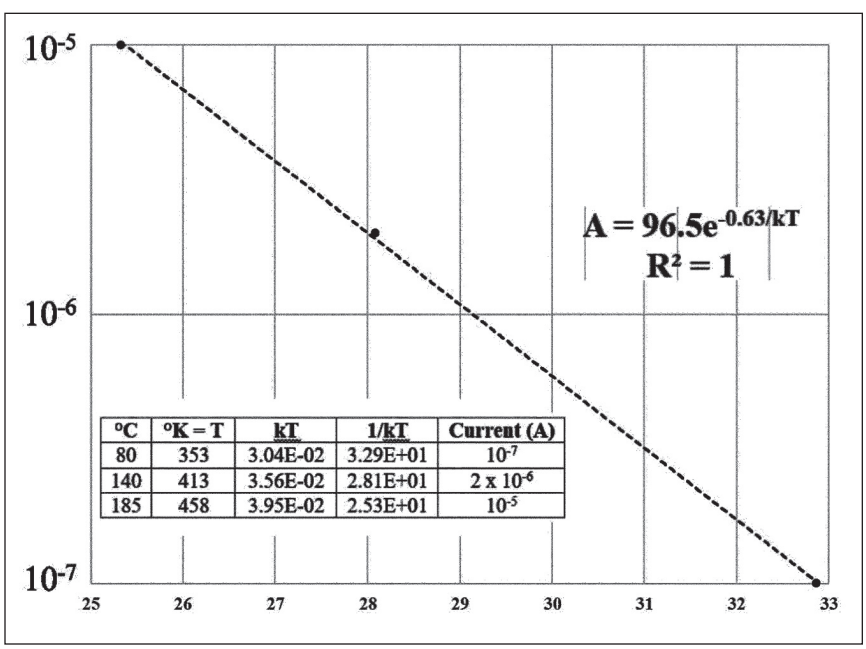
Hydrogen Ion Diffusion. As noted above, David and Giles started experiments on direct production of electricity using LENR energy. David remains active in the field, and recently published a possible explanation of the mechanism active in LEC devices. His concept can be understood with the schematic in Figure 17.[53] It shows palladium as an electrode in a LEC, although the idea applies equally to a palladium or other deposit that contains hydrogen ions. The occurrence of LENR within the active electrode leads to the production of an H_2^+ ion on the surface of the electrode. Such ions leave the active electrode with a net positive charge. If it detaches, the molecular ion can diffuse to the counter electrode, and pick up an electron. A light ion, like H_2^+, will have a relatively large diffusion coefficient. Neutralization of the ion induces a net positive charge on the counter electrode. The resulting charge separation can drive a load, as indicated in the figure.

Gordon and Whitehouse[33] have presented data on the temperature variation of the constant load current at low load resistances, as shown in Figure 18. There are two interesting implications of the plot in Figure 18. One is the excellent fit of the three data points to an Arrhenius equation, which indicates an activated diffusion process. While that does not rule out the possibility of the inter-electrode gap being spanned kinetically by energetic particles, the fit favors the diffusive mechanism of David shown in Figure 16. The activation energy of 0.63 eV that results from this plot seems high for the movement of H_2^+ molecules in air.

The charge flow indicated in Figure 16 is like that in some fuel cells[54] with Proton Exchange Membranes (PEM).[55] In them, H_2 fuel molecules dissociate into H atoms at the anode, which then lose electrons to become protons. The protons diffuse through the PEM to the cathode where they pick up electrons and combine with O_2 to form water. The electrons from the anode move to the cathode of the fuel cell through the external load, like the electron flow shown in Figure 16. The energy produced in fuel cells is due to the lower energy of water molecules compared to the H_2 and O_2 gases. According to David, the energy from LEC devices is due to the occurrence of LENR, which produces the H_2^+ ions. A way to test David's concept will be outlined below.

Analyses. The lack of a means to produce charge separation within a LEC argues against an ionization mechanism. And, the fact that LEC devices can work with different gases in them is apparently not consistent with an ionization mechanism. Overall, these two points, and the discussion above, appear to leave us with two major possibilities for the mechanism that is operative in LEC devices, kinetic charge transfer and hydrogen molecular ion diffusion. It is possible to examine both of those mechanisms in a systematic manner on a uniform basis. That is done in the following paragraphs.

The voltage that appears between the WE and CE depends on the rate and duration of charges that are (a) produced by the WE, (b) transported successfully between the WE and CE, and (c) absorbed by the CE. First, the rate of charge pro-



°C	°K = T	kT	1/kT	Current (A)
80	353	3.04E-02	3.29E+01	10^{-7}
140	413	3.56E-02	2.81E+01	2×10^{-6}
185	458	3.95E-02	2.53E+01	10^{-5}

Figure 18. Temperature dependence of the LEC current in log Amps vertically vs 1/kT horizontally, where k = Boltzmann's Constant and T is the absolute temperature. The plot shows the behavior of an Arrhenius plot with an activation energy of 0.63 eV.

duction from the WE depends on two factors, the rate of LENR that occur close to the surface of the WE and the multiplication factor that gives the number of emitted charges per LENR event. Second, the transport of charges across the inter-electrode gap depends on two kinds of factors, some associated with the charge and some with the ambient gas in the gap. The type of charge and its energy are both relevant to the transport efficiency. And, the type of gas (H_2, air, etc.) and pressure must also be important. Third, the number of charges that arrive at the CE might not be the number that are captured due to surface losses or the excitation of additional charges for impact of energetic charges. Overall, both production numbers and transport efficiencies are important.

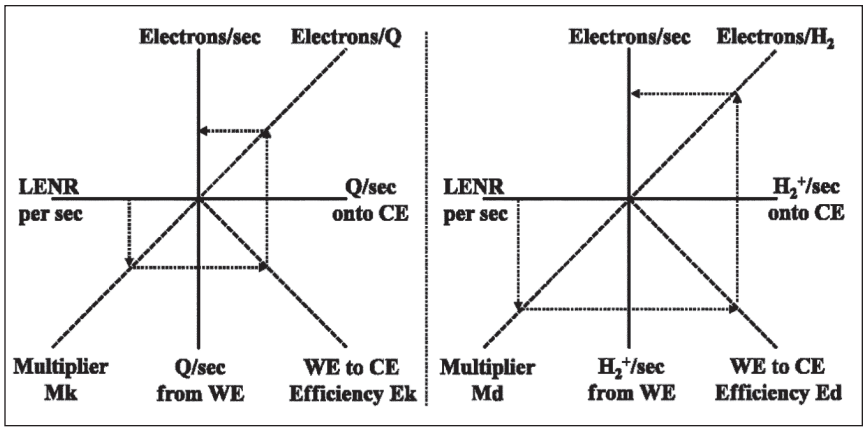


Figure 19. Schematic plots for the factors in equations relevant to two potential LEC mechanisms. Left: plots for kinetic charge transfer. Right: plots for hydrogen molecular diffusion. Both sides represent three log-log plots in all quadrants except the upper left region. The arrows on the left diagram show that a low LENR rate will lead to a low current. Similarly, the arrows on the right link a high LENR rate to a high current. See text for the equations and explanations.

Figure 19 contains two sketches based on the equations for estimating the electrical current (electrons/sec) from the rate of nuclear reactions (LENR/sec) for the two mechanisms. This method of making graphical presentations of equations was developed at ICCF13 for computing LENR rates on surfaces of metals.[56] The three plots show four factors indicated by the solid axes and three efficiencies, one in each plot, as indicated by the dashed lines. It enables the determination of some of the factors in the equations based on known values of other factors.

The LEC Current for kinetic mechanism depends on the following factors: (Electrons/Q), Ek, Mk and (LENR/sec). Q stands for quanta produced in the WE at the rate of Mk quanta per LENR reaction, which are emitted by WE, pass to the CE with efficiency Ek, and produce electrons at the rate (Electrons/Q). The last rate might be unity if the quanta that pass from the WE to the CE do not impact with energy sufficient to free additional charges. The equation for the steady state kinetic LEC mechanism is:

$$\text{LEC Current} = (\text{Electrons/Q}) \times Ek \times Mk \times (\text{LENR/sec})$$

In a similar fashion the current for the diffusive LEC mechanism depends on the following factors: (Electrons/ H_2^+), Ed, Md and (LENR/sec). The definition of terms in the second equation is like those in the first equations, with the diffusion H_2^+ in place of the energetic quanta Q. Again, there are two important factors, the multiplier Md and the transport efficiency Ed. There should be only one electron left in the CE per incident hydrogen molecular ion, as shown in Figure 17. The equation for the steady state diffusive LEC mechanism is:

$$\text{LEC Current} = (\text{Electrons/ } H_2^+) \times Ed \times Md \times (\text{LENR/sec})$$

The utility of the plots in Figure 19 can be illustrated by using them to relate the measured current (Electrons/sec) to the nuclear reaction rate (LENR/sec). That requires making estimates of the three efficiencies in the equations and plots. Having all three for each plot fully determines all the factors. One of the efficiencies can be estimated with confidence, namely the number of electrons per hydrogen molecular ion H_2^+. It can be taken as unity. The number of electrons produced per incident quanta Q might also be unity, but could be higher if the quanta still had significant energy when they reach the CE. The transport efficiencies E of quanta or ions between the electrodes is less certain. However, both can be taken to be a relatively large probability, maybe in the range from 0.1 to 0.5. The least known factor is the number of energetic quanta or molecular ions M that are produced per LENR reaction in the working electrode. Those factors could be less than unity. However, the fact that the energetic output of nuclear reactions is in the MeV range means that those factors could be much larger than unity. It might be that the products (Mk x Ek) and (Md x Ed) are in the range of 1 to 100. If that were true, then the output current in (Electrons/sec) would be larger than the value of (LENR/sec) by similar factors.

Examination of the actual current measurements show that the considerations in the last paragraph need modification. As already noted, 10 μA of LEC current is about 6×10^{13} electrons per second.

If the ratio of Electrons to LENR were 20, the LENR rate would be about 3×10^{12}/sec. If 24 MeV is released in each LENR reaction, the value for deuteron fusion, that LENR rate would correspond to 10 W, an easily measured LENR power. A LENR power of 10 W would raise the temperature of the working electrode to values higher than observed. Hence, we need to modify the estimates of LENR rates by adjusting the products (Mk x Ek) and (Md x Ed) to much larger values, maybe greater than 1000. That would require Multipliers M well above 1000, since the efficiencies E are less than unity.

It is not possible now to determine computationally if either of the two potential LEC mechanisms, kinetic or diffusive, is correct, or if not, what other mechanism might be active in LEC devices. However, it seems possible that experiments could be designed to learn more about the active mechanisms.

■ ***Potential Experiments with LEC Devices.*** Some scientists have already expressed opinions on new LEC experiments to understand their behavior and understand their mechanism(s). A few are summarized in the following paragraphs.

Zhang posted a summary of a meeting of Chinese cold

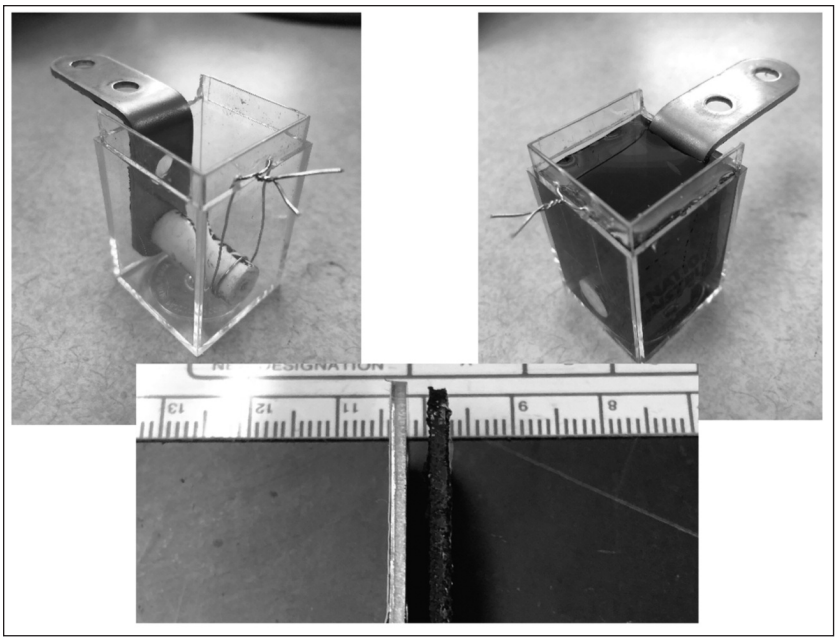


Figure 20. Top: Photographs of a Lucite cell before and after filling with a $PdCl_2$ and LiCl heavy-water electrolyte, followed by co-deposition of palladium and deuterium. Bottom: Image of the coated and blackened bracket on the right spaced 2 mm from a counter electrode on the left.

fusion scientists on the LENR-Forum in mid-October of 2022.[57] He wrote that the group would like to see the following experiments done on LEC devices: "1. Influence of plate spacing on LEC. 2. Influence of plate area on LEC. 3. If a piece of paper is inserted between electrodes, whether there is voltage. 4. Test the short-circuit current. 5. Whether the dryness and insulation of joints and insulation supports affect the test (excluding chemical batteries and thermocouples)." The first four of these points involve possible parametric experiments on LEC devices. The last concerns the still-extant question about whether the voltages produced by LECs are chemical or nuclear in origin.

The experiments already reported on variation of the LEC electrode spacing and area have been done with the usual cylindrical geometry. However, there is significant advantage in using flat plates for such experiments. The flat plates can be oriented either horizontally or vertically. Both options have been considered by this author, as noted in the following paragraphs.

Smith did experiments with flat LEC electrodes. In March of 2022, the following was written to Smith by this author in an email about experiments with horizontal flat plates: "You are in a good position to do two important experiments. One would be to vary the gap between plates by using different numbers of cover glasses, assuming your plates are flat. I think that the variation in the voltage with spacing would be a valuable piece of data for understanding the LEC. Another experiment would be to vary the area of the plates. You could set up a system without a central spacer, and insert an insulator (plastic sheet or maybe even paper) to see how the voltage varies with area. Both of these experiments would be influenced by the uniformity of the activity on the working electrode."

It now seems that using vertically-oriented flat plates would have some advantages. One is the ability to easily vary the interelectrode spacing. Figure 20 shows images of the co-deposition of palladium and deuterium on a commercial iron alloy bracket. The test failed to evidence any voltage. That might have been due to (a) an ineffective deposit, (b) too large a spacing or (c) escape of H_2^+ ions into the atmosphere above the electrodes.

The last possibility suggests another experiment, which is sketched in Figure 21. If the escape of hydrogen molecular ions was responsible for the failure of the experiment just noted, controlling such escape should be easy. Placing the LEC electrodes vertically, like the brackets in Figure 19, and then covering them with a plastic barrier, would stop the escape of the H_2^+ ions. If the plastic barrier were in place, the LEC voltage could develop in the diffusion mechanism. Removing the barrier would permit escape of the H_2^+ ions, stopping voltage generation. Repositioning the barrier would enable measurement of the time it takes to re-establish internal equilibrium and a constant voltage output.

The schematic in Figure 21 could also enable another experiment. If the movement of energetic charged particles from the working to the counter electrode were part or all of the reason for LEC voltages, applying an electric field might influence the motion of the ions and, hence, the time variation of the LEC output voltage. The black lines in Figure 20 indicate the positions of flat electrodes to which DC or variable voltages could be applied. If the active deposit on the working electrode were confined to a narrow strip, as indicated in the figure, ions leaving it might be significantly altered in their trajectories, depending on the type of charges, their energy, the field strength, and the atmosphere and pressure within the LEC. Also, it would be possible to have two parallel wires, one on or in the surface of each electrode, with the one on the working electrode activated with a coating. Then, varying the exterior field strength might produce a significant modulation of the LEC output.

It seems clear now that the LEC can be a valuable LENR research tool, whether or not it can ever be scaled to outputs that are practically useful in both power and duration with the needed control.

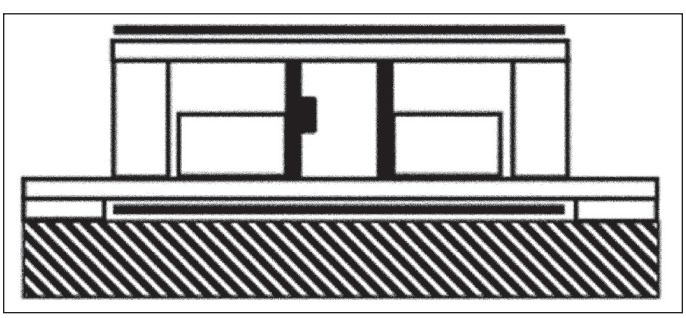


Figure 21. Cross section of two potential experiments in which the LEC electrodes (the vertical black lines) viewed from their ends are oriented vertically, and the working electrode on the left has a deposit on its inner surface (the black lump). The cross-hatched area is the lab bench, and the horizontal black lines are electrodes for the application of electric fields to the interior of the LEC. The open boxes with black outlines are all plastic pieces. The inner two plastic supports are attached to the metallic electrodes to hold them upright.

5. Direct Conversion Systems with Gaps and Plasmas

The gas within a LEC might be partly ionized, but it is more of a little-ionized gas than a plasma due to its low temperature. There is another class of direct electrical production devices that has a gap between two metallic electrodes. However, in this other class, the gap is partly filled, at least occasionally, with a hot plasma. We will first review some old experiments of this type, before reviewing a modern version of such an experiment.

■ ***Early Papers Relevant to Direct Electricity Production.*** The history of LENR apparently includes several papers from long before the Fleischmann-Pons announcement, which contain evidence that is possibly due to nuclear reactions from low energy experiments. It was noted that various old papers reported thermal energy, reaction products and electrical production. Here we return in more detail to the early papers on production of voltages by the apparent nuclear reactions. This has two advantages. For one, it permits comparisons with the post-1989 papers on direct production, which are discussed in this paper. And, it sets the stage for examination of recent reports from Egely on his development of a modern system for amplification of electrical power by use of LENR.

Egely has long been a student of papers that reported odd and possibly nuclear effects during the 20th century, long before 1989. He has published many articles on those early reports in *Infinite Energy*. During the ICCF24 presentation, Egely listed eight of his *Infinite Energy* articles that should be read to better understand the system he reported at ICCF24. They are all titled "Faces of LENR," with sub-titles summarized in Table 2. He also cited two specific old papers that are relevant to his system.[58]

The subtitles make clear that the eight articles are in two categories. The first group (Parts 1-4) has to do with science thought to be important to the second set of four articles (Parts 5A-D). The lengths of the eight papers are noteworthy. They are very detailed and well referenced.

Egely summarized the contents of the initial four articles (Parts 1-4) in Part 5A, as follows:

> In Part 1, the extension of electrodynamics was accomplished by including rotation. Thus, the formation mechanism of condensed plasmoids as torus-like heavy quasi-particles was described. In Part 2, rotating charged dust particles were described as a means of the most-simple LENR processes in nature; it is the means of energy production in the solar corona, and the ATP synthase, to turn deuterium and carbon into nitrogen. In Part 3, electrodynamics was extended to include a generalized Lorentz force, capable of teleportation. This may explain transmutation/fusion of heavy nuclei, and the Hutchison effect. In Part 4, the rich features of ether were described. It was claimed that ether consists partly of neutrinos as a frictionless superfluid at macroscopic distances. At subatomic distances, ether is a randomly oscillating high-density medium, made of electromagnetic oscillations. No isolated system can exist due to its high penetration capability. Therefore, the rules of thermodynamics are just approximations, not laws.

It is clear that Egely's views go well beyond what he terms as "textbook physics" regarding both concepts and terminology. Explanations of some of the less familiar terms can be found as follows: plasmoids,[59] quasi-particles,[60] ATP synthase,[61] teleportation,[62] Huchinson Effect[63] and ether.[64]

The word "plasmoid" will come up repeatedly in the rest of this review, so we pause to provide some information on it.[65] It was coined by Bostick in 1956[66] when he wrote the following about some of his experiments: "The plasma is emitted not as an amorphous blob, but in the form of a torus. We shall take the liberty of calling this toroidal structure a plasmoid, a word which means plasma-magnetic entity. The word plasmoid will be employed as a generic term for all plasma-magnetic entities." The term "condensed plasmoid" was developed by Jaitner, who wrote[67]:

> The term "condensed plasmoid (CP)" is coined in this document for the first time, thus a definition is given here. A CP is defined to be a plasmoid (*i.e.*, a self-consistent structure of a current-carrying plasma and magnetic fields), which is meeting all of the following criteria:
>
> • The plasmoid is compressed by a strong z-pinch condition. "Strong" in this sense means that the internal current is larger than 200 A, the radius of the plasma channel is less than 200 pm and the length of the plasma channel is at least several micrometers.
> • All electrons of the containing atoms (not merely the outer electron shells) are delocalized, *i.e.*, the electrons are all contributing to the current and they can freely move between the atomic nuclei. The delocalization is caused by the small inter-nucleic distance (*i.e.*, less than 10 pm in case of hydrogen).
> • The electrons are residing in orbitals, which are at (or near) the quantum-mechanical ground state of the CP. For this to be true, the temperature of the CP must be low enough, that the thermal pressure of the plasma is smaller than the magnetic pressure enforced on the moving electron gas by the Lorentz force. The properties of CPs therefore do not always follow the conventional wisdom of plasma physics.
>
> CPs exist in different topologies:
>
> • The open-ended configuration of a CP exists under transient conditions in presence of a strong electric field.
> • The closed-loop configuration of a CP is the long-lasting form, where the internal current is flowing in a circular manner.

While Egely's perspective bothers many scientists, it is

Table 2. Articles by Egely on old reports of unusual and possibly nuclear phenomena.

Sub-Title	Issue	Pages	Date
Part 1: From Alchemy to Biological Transmutations	151/2	15-26	May/Aug 2020
Part 2: From Alchemy to Biological Transmutations	153	16-31	Sep/Oct 2020
Part 3: From Alchemy to Biological Transmutations	154	8-26	Nov/Dec 2020
Part 4: From Alchemy to Biological Transmutations	155	9-22	Jan/Feb 2021
Part 5A: Design and Operation Principles of LENR Reactors	156	9-26	Mar-Jun 2021
Part 5B: Design and Operation Principles of LENR Reactors	157	23-43	Jul/Aug 2021
Part 5C: Design and Operation Principles of LENR Reactors	158	27-47	Sep/Oct 2021
Part 5D: Design and Operation Principles of LENR Reactors	159	13-27	Nov 2021-Feb 2022

part of one of the most fundamental questions about LENR. That question asks whether LENR can be understood based only on the Standard Model of physics. Some LENR theorists think that it is necessary to go beyond that generally accepted, but still intensely-studied, model to understand LENR. The durable impact of LENR on physics, and science more broadly, will depend on the ultimate answer to that question. We do not need to have the answer to the basic question about understanding LENR to consider the important topics of the "Design and Operation Principles of LENR Reactors." Basically, the science of LENR is proceeding in parallel with the engineering and even commercialization of LENR. There are two motivations for the early attention to exploitation of LENR that are clear. They are the possibility of immense profits and the urgency due to the many dire effects of climate change.

Egely started Part 5A with a clear explanation of what he means by the "faces" of LENR:

> Parts 5A (herein) and 5B (forthcoming) discuss the dominant types (faces) of LENR reactors: 1. Heat generating reactors, triggered mainly by fission, induced by cracking (hydrogen corrosion) of the lattice. The Pons-Fleischmann cell belongs to this group (Part 5A). 2. The second reactor group is dominated by transmutations of even heavy elements; it is marked by rotating charged dust particles (Part 5A). 3. The third face of LENR is dominated by electric energy generation by surface plasmon and condensed plasmoid-based reactors. Their technical layout and energy extraction methods are also discussed. This is applied physics and engineering (Part 5B).

We provide brief reviews of the four parts of Paper 5 in the following paragraphs. Most of what is in the papers is on energy generation and transmutations. However, the papers also deal with direct electrical production, especially Paper 5C.

Since Egely is concerned with all three of the faces of LENR, he devoted Paper 5A to review of devices for heat generation and production of new elements. He started with listing and arguing against four myths about LENR. However, the focus of the article is on LENR reactors, as indicated by the subtitle. Egely wrote, "The physics in all previous four parts will be used because LENR reactors cannot be understood, designed and operated without them. All LENR reactors have one common feature: they are based on catalytic effects. The careful design and operation of LENR reactors opens vast new opportunities to improve upon the catalytic fusion effects to make marketable products." He listed three areas of LENR catalysis, as follows: "1. Neutron-catalyzed fusion in a lattice: Metal lattice vibrations caused by cracking due to hydrogen diffusion, or hydrogen corrosion, led to fission. Fission yields neutrons participating in fusion. 2. Rotating charged dust as a catalyst: Dust fusion, when rotating, charged particles generate electric, magnetic and spin fields as a catalyst. 3. Condensed plasmoids and plasmons as a catalyst: Quasi-particle catalyzed fusion characterized by the combination of surface plasmon waves and condensed plasmoids. They are formed only in transient plasma microdischarges, a barely researched area of plasma physics." It is interesting that Egely believes that cracking is a requirement for what might be termed as usual LENR experiments involving electrochemical or other loading methods. He notes that "continuous cracking cannot be maintained for years. This is the ultimate bottleneck of diffusion controlled LENR reactors."

The bulk of Paper 5A is on the analyses of many different experiments for generation of heat or nuclear reaction products. Egely expresses clear opinions on his view of the value of some of them. He goes into detail on experiments that involve both dusty plasmas (plasmas containing small solid or liquid particles) and resonant conditions. Egely has worked extensively and successively with both conditions.

Paper 5B from Egely starts with this abstract summarizing its contents and putting it in context:

> While in Part 5A we mainly discussed the reactors based on electrolysis that were at the center of research for decades, a new field of reactors based on dusty plasma was also discussed. We move into a new area in Part 5B: LENR reactors based on quasi-particles. Though plasmon polaritons and condensed plasmoids were frequently mentioned in all previous parts, we shall move towards their practical applications. First the landscape of mainstream transient plasma research is shown. There the streamers of corona and spark discharges are known to produce heavy negative quasi-particles. However, they have never been tested for catalytic nuclear fusion, just as chemical catalysts. We shall review spark related research, as this area is shown to induce fusion effects. Most of the results have been published in peer-reviewed journals, like *Fusion Technology*. The most important results have come from the papers of Matsumoto, Karabut and Dufour. The most important patents were granted to Shoulders. These results were published mainly in the 1990s, the "golden age" of LENR research.

This paper starts with a bold statement: "Heat generation is a relatively simple LENR process, and so is chemical (oxygas) energy generation. Other processes, like electrical energy generation, require additional steps to extract the generated excess energy." Paper 5B contains a very useful table in which the characteristics of a dozen demonstration experiments from the last century are presented. All of them involve micro-discharges, with diverse cathode designs, cavities and plasma compositions. Nine of the listed devices involved the production of electricity, two have mechanical outputs and one produced the energetic chemical oxygas.

Paper 5C by Egely contains much information on the direct generation of electricity from nuclear reactions. It starts with Egely's summary of his taxonomy of the three main ways to achieve LENR:

> Mechanism 1 — Fission of nuclei is due to cracks induced by diffusion and lattice vibrations. This is the fundamental process of electrolysis-based Pons-Fleischmann cells. Decisive tests were carried out by an Italian group led by Prof. Alberto Carpinteri… Mechanism 2 — Dusty plasma fusion: that is, catalytic fusion by rotating, electrically charged dust particles. This process runs the energy generation of the whole Universe, in the thin halo, in the corona of stars. The dust is supplied by the omnipresent low-density inter-

> stellar dust…Catalytic Fusion by Quasi-particles. Truly disruptive green energy innovations (Mechanism 3) are run by quasi-particles, like condensed plasmoids, and plasmon-polaritons.

It is clear that Egely believes that the third method involving the production of quasi-particles in electrical discharges is most relevant to direct production of voltages. He wrote:

> The direct production of electricity (without intermediary heat engines) is a distant area from all previous LENR methods. The experience gained in Pons-Fleischmann cells, or dusty plasma reactors, is not of much help here. These areas are far from the borders of textbook plasma physics, and from each other as well. Therefore, the spark-based experimental work demands a different set of background skills and know-how than the other fields of LENR.

Egely made an interesting point about piecing together a coherent picture from disconnected reports. That is one of the greatest challenges for the understanding of LENR. On that point, he wrote: "All inventions in this area have only fragmented information about their technical details. However, reading them will be like solving a crossword puzzle. The solution will emerge gradually, when the missing information is filled by adding the fragments learned by other inventions." Egely has studied many reports, papers and patents to gain the "missing information."

The old work most relevant to Egely's recent development of an electricity amplifier was done by the well-known Tesla and a little-known fellow named Moray. Moray was experimenting with what was called a "crystal radio," a homemade radio receiver that could easily be made by hobbyists. The key component of the radio was a diode that usually consists of a natural semiconductor mineral, commonly Galena (PbS), and a fine wire (called a "cat whisker"). Placing the wire onto an active spot on the crystal to achieve "rectification" of the signal from an antenna was an art, but it could usually be done successfully. Rectification eliminated the alternating, high frequency radio carrier waves, leaving the desired sound waves at the lower audio frequencies. Moray observed that he could hear a series of clicks in his headphones even when the wire was not in contact with the crystal. Egely attributes that to the occurrence of discharges in the small gap, which broke down water (humidity) in the air, and led to fusion and electrical power sufficient to be heard in the headphones. His Paper 5C shows oscilloscope traces from his experiments that could sound like a series of clicks.

Egely wrote the following comments on the two most successful experimenters:

> All in all, both Tesla and Moray faced and solved three problems: 1. To form condensed plasmoids with efficient spark discharge. 2. To force the condensed plasmoids to catalyze fusion of hydrogen nuclei by transient external electric fields (perhaps also magnetic fields). 3. To capture the high-energy electrons ejected from the condensed plasmoids in the form of potential electric energy.

The Paper 5C discusses each of the three steps in some detail. The need to match the behavior of the production of energetic electrons to the ability of the downstream circuitry to capture them is made clear. The requirement for (a) proper and (b) coordinated action of all three steps makes clear the challenges of engineering systems to amplify electrical power using energy from LENR.

Overall, Paper 5C is a valuable resource to understand Egely's views on direct production of electricity from LENR and to begin to engineer prototypes for that purpose.

Early material in Egely's Paper 5D provides a useful summary of its three types of contents:

> 1) A brief section on "second rate" inventions, where even less is known about the design and operation parameters. Though hundreds of such inventions were patented during the last 150 or so years, all of them are buried on the shelves of patent offices. 2) Condensed plasmoid-based mechanical inventions "fueled" by the ambient vapor in the air. As usual, these spark-based rotary devices all resemble Wimhurst devices—electrostatic influence machines. 3) The similarity laws between discharges are briefly discussed, because they are needed to have a firm ground for LENR reactor design in transient gas discharge. The attitude and beliefs of inventors and academic researchers are in strong contrast to each other. There is no communication, no "bridge" between them. The forgotten inventions should be fertile soil for academic research. There is no communication even among academic researchers, *e.g.*, condensed plasmoids were discovered (and forgotten) at least eight times.

This paper has two useful tables. One compares the features of LENR induced by (a) loading of hydrogen by electrochemical and thermal method into a lattice, (b) rotating charged dust particles in plasmas and (c) transient sparking or micro-discharges that produced condensed plasmoids. The second table compares the practical merit and main parameters of five types of fusion reactors, the three mentioned in the previous sentence, plus both inertial and magnetic hot fusion. This paper does not focus on direct electrical generation with energy from LENR.

■ ***Recent Developments by Egely.*** A paper presented by Egely at ICCF24 summarized some remarkable results. The abstract contains the following statements, where COP is the Coefficient of Performance, that is, the energy gain:

> A system is presented consisting of three parts: (1) Pulsed voltage input, (2) The reactor tube using spark discharge in hydrogen isotope gas, and (3) A harvesting circuit, which is an impedance matching device, like a gearbox in a car. The LENR process takes place during and after a spark discharge. We built a small system due to financial limitations, where the input current is in the μA range, and the voltage doesn't exceed 3 kV. After the LENR process during the sparking, the output appears as fast, high-voltage pulses of up to 30 kV, thus limiting digital data acquisition. In order to have reliable power balance data, both the input and the output pulsed currents flow through thermostated ohmic resistors. Thus, the time-averaged input and output electric

power is measured in a conservative manner by calorimetry. Only the electric energy output (turned into heat by the resistors) is considered, all other output energy forms like heat, sound, or light were neglected. Usually, the output/input COP is 3-4, but under perfect resonant matches we measured COP up to 10. The effect appears only in a disturbingly narrow range of parameters like pressure, electrode distances, voltage, harvesting impedance and plasma acoustic resonance.

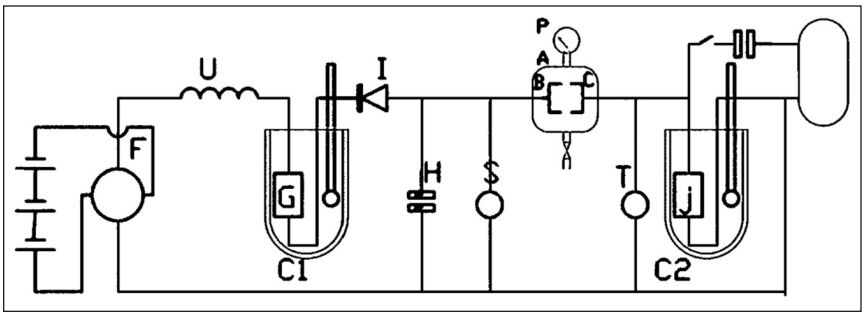


Figure 22. Circuit diagram for the input to and output from the discharge tube, which has a gas input in the bottom and a pressure gauge on the top. See text for details.

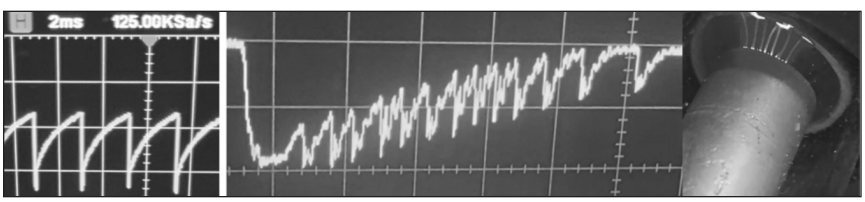


Figure 23. Left: Oscilloscope trace of the input to the discharge tube, where the time scale is 2 ms per divisions and vertical scale is 1 kV per division. Center: Trace of one output pulse at 0.5 ms and 1 kV per division. Right: Photograph of the electrodes in the discharge tube during operation showing multiple discharge arcs.

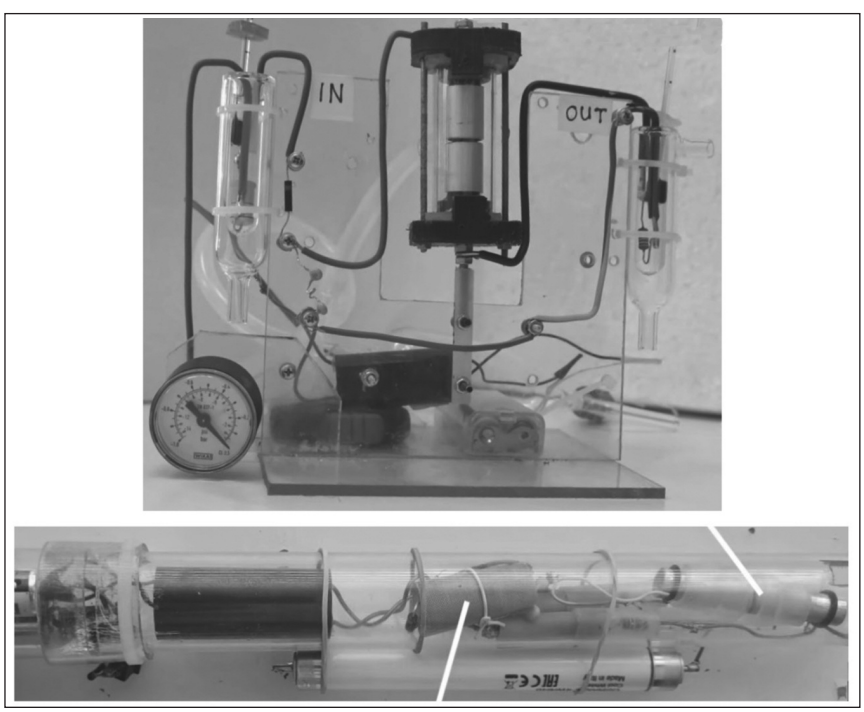


Figure 24. Top: Experimental version of the Egely system, showing the pressure gauge and electronics near the bottom, the two calorimeters labelled IN and OUT, and the discharge tube in the top center. Bottom: A portable version of the system in a plastic tube, with three batteries only partially visible on the left, a high-voltage transformer in black, and inductor (marked with the central white line) over the two calorimeters, the discharge tube on the right (marked with the right white line) and a fluorescent tube load at the bottom.

At the time of this writing, a paper on his ICCF24 presentation from Egely is not yet available. However, a video of this presentation is on YouTube.[68] It provides the basis for a more detailed summary of what he reported, as follows.

The diagram of the circuit for Egely's system is in Figure 22. The pulsed voltage input is generated by the components on the left. The reactor tube A with its electrodes B and C is shown with a pressure gauge P on its top and valved gas inlet on its bottom. The output part of the circuit and the load in the oval are on the right. The two large and similar structures within the circuit are calorimeters for measuring the input power (left) and the output power (right). Each calorimeter is a liquid-filled vessel, which contains a resistor (G and J) and a thermometer.

The waveforms recorded by Egely are shown in Figure 23. The input is a sawtooth waveform with a 2 ms width. The output waveform is like the input time history, but has many short (roughly 200 µsec) spikes superimposed on the longer (about 2 ms) waveform. The lightning-like discharges that can be seen between the electrodes in the image in Figure 22 must be the source of the small fast output voltage peaks.

The video contains images of two embodiments of Egely's system, which are shown in Figure 24. A laboratory version is on the top, and a portable version in a plastic tube is on the bottom. Such systems have been measured to give a ratio of power OUT to power IN from 2 to 20, which can be higher "with feedback." Electrical power gain is realized with a mixture of H_2 and D_2 gas in the discharge tube. With dry air or helium, the system does not give electrical power gain.

During the presentation, Egely stated that the areal power density is on the order of MW per mm^2, although where the area is measured is unclear. It might be the edges of the two tubes that make up the electrodes, as shown on the right in Figure 23. Importantly, the output is not steady, but consists of pulses that are on the range of ns to µs in width, with a duty cycle of 10^{-3}. Egely said that it will be possible to make a 1 +/- 0.5 kW system with very little heat. He estimated that the manufacturing cost of such a system would be about $100 per kW. It is noted that the fast pulses of tens of kV would require some power modification circuit to produce outputs that are acceptable to most electrical equipment.

Egely believes that the system works because of the production and effects of clusters of charge, which have been postulated by Shoulders[69] and Mesyats.[70] He cited a book by Raether,[71] in which one graph showed that

the charge clusters contain one hundred million to a few billion electrons. Egely stated that it took him 40 years to "figure out that this is a catalytic fusion process." He stated that the strongly negative clusters accelerate protons, giving them at least the additional 780 keV that is needed to produce neutrons. That reaction is the reverse of the well-known neutron decay reaction. It is unclear where the electron neutrino postulated as part of the input to the neutron-production reaction originates. The sun emits neutrinos at high rates,[72] but their density on the surface of the Earth is not sufficient for high rates of laboratory nuclear reactions. Thermal neutrinos are produced in stars, but not on Earth.[73] The produced neutrons can then go on to react with other nearby nuclei. For example, its reaction with a proton will give deuterium, and a reaction with deuterium will produce tritium. The overall scheme of neutron production is reminiscent of the ideas of Widom and Larsen,[74] although the physical mechanism is very different.

A company in New Zealand is seeking to commercialize LENR generators based on Egely's prototypes. It is Gaia Energy Ltd.[75] The website of the company shows an artist's impression of what their generator might be like. It could be about "the size and weight of a home office printer." Figure 25 is an edited version of the concept from the company's website. The electrical circuits for input and output are in the front of the housing. Presumably, the "Harvest Circuit" would provide the needed waveform modification to produce usable outputs. The key components, multiple discharge tubes, are in the cylinder in the back.

The system devised and reported on by Egely clearly needs two types of attention. One is independent testing of his prototype. Such testing would be a normal part of the development of the technology. The other requirement is commercialization, including the development, testing, redesign, testing and manufacturing of units for customers. Such commercialization involves many steps, which are outlined and discussed in an article in this magazine.[76]

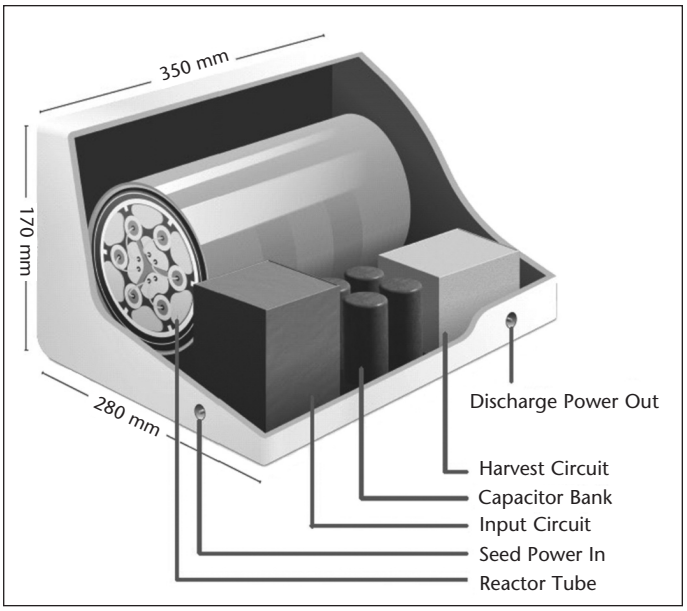


Figure 25. Drawing of the conceptual Gaia Energy LENR-based battery charger.

6. Summary and Comments

A simple tabular summary of the advantages and challenges for the devices reviewed in this paper is shown in Table 3. It is seen that the devices fall into two main categories according to their power outputs.

Examination of the results from the several devices gives some of their general characteristics. One of them is the generally erratic and uncontrollable output characteristics (voltages, currents and powers). Achievement of the control to enable desired outputs for various applications is a clear need. The scaling up of the output power of direct conversion devices, as discussed by Gordon and Whitehouse, is another of the issues in this field. Also, the mechanism(s) by which the various direct conversion devices work remain to be determined with high certainty. As noted, it is still unclear whether or not any or all of the direct conversion devices involve only nuclear reactions, that is, LENR. There is still concern that some aspects of performance for some devices might be due to chemistry. That seems unlikely, but remains to be proven experimentally. Even if that is the case, such devices might still be useful for the scientific study of LENR, regardless of their ultimate practical potential.

Three things are certain now: (a) most direct conversion devices have an uncertain future, at least practically, and maybe even scientifically; (b) the need for parametric studies and the use of additional instrumentation to provide a stronger experimental base for understanding direct production of electricity by LENR, and (c) specific tests of theoretical ideas, for example, the mechanism(s) operative in LEC devices. If some direct electrical production experiments start to develop practical promise, they will need serious engineering to be turned into, first prototypes, and then products.

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Table 3. Comparison of LENR technologies for direct production of electricity.

Technology	Advantages	Challenges
Fusion Diodes	Spontaneous production of low electrical power in relatively simple devices	Increasing output power to useful levels and achieving control for practical times.
NANORs™		
BioSearch Devices		
Lattice Energy Converters		
Egely System	Higher powers and high amplification factors	Control, validation and commercialization

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