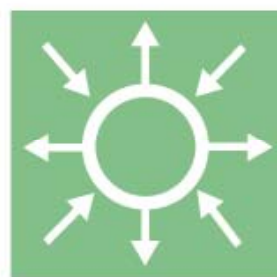
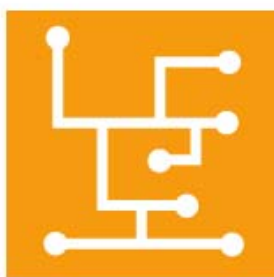




Low-energy nuclear reactions

A status overview summary of a
controversial phenomenon

Elforsk rapport 13:901



Margaretha Engström, Sten Bergman

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ELFORSK

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Preface

Elforsk (the Swedish Association of Electrical Utilities), which is jointly owned by the electrical power industry, provides a common forum and facility to discuss and investigate matters of strategic importance which may have a considerable effect on tomorrow's energy systems. Elforsk's Strategies and Systems programme area monitors current research and development in order to keep the industry up to date on important advances, and to provide the necessary knowledge to be able to question or support further development.

Low-energy nuclear reactions, LENR, is a working area that has attracted increased attention over the last two or three years. When a dozen companies state that they are concentrating on commercialisation of LENR technology, it can possibly indicate that something unexpected has been discovered, and that this discovery could, in future, affect energy supply to society.

For Elforsk, this is not a matter of deciding whether the LENR phenomenon exists or not, but of being prepared in case the unexpected should happen. Theories accounting for the phenomenon are still fluid, with practical verification of the function being an area of work in continuous progress.

This report, which has been written by Margaretha Engström of Vattenfall Research and Development, and Sten Bergman, of StonePower AB, is an overview presentation of information from various sources of LENR technology. It does not make any value judgements concerning scientific rigour.

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2013-11-15

Summary

Are we on the threshold of a new era in respect of sustainable, low environmental impact energy supply? Is there something new around the corner that could revolutionise our way of producing heat and electricity, or of powering tomorrow's vehicles? These are questions that should now be considered as a result of the renewed interest again being shown in low-energy nuclear reactions.

This report is an overall summary review of the Low-energy nuclear reactions working area or, as it is sometimes called, Cold Fusion. Equipment and devices, based on LENR technology, are now beginning to be demonstrated here and there in the world. In some cases, the energy yield from these devices is claimed substantially to exceed the input energy needed in order to start and stabilize the process. If this is true – which has been questioned by many – we are looking at something unexpected: that this is perhaps a new process that greatly exceeds conventional fuel-based energy conversion processes. In addition, these devices are claimed to operate without significant environmental impact. Or are the results that are now being claimed the consequences of incorrect measurements and wishful thinking?

Some events along the way:

- Andrea Rossi, an Italian inventor and chemist, has developed a reactor to which he has given the name E-Cat. It is an apparently simple apparatus, consisting of a metal tube containing a small quantity of catalyst in the form of nano-size nickel powder. To start the process, the tube is filled with small quantities of hydrogen and other elements, and then delivers a substantial thermal output over a period of several months. The company that is developing Rossi's device, Leonardo Corporation, claims that its reactors will soon be "scientifically" validated and ready for a market launch.
- The Greek company, Defkalion, which is nowadays based in Canada, was originally working with Andrea Rossi, but has now branched out on its own to develop the Hyperion hydrogen/nickel reactor. The company has announced that its technology will launch in 2014.
- Brillouin Energy Corporation, an American company, claims that it has discovered what it calls the "*controlled electron-capture reaction*".
- As far back as the 1970s, Joseph Papp claimed that energy could be obtained through the compression and electromagnetic stimulation of an inert gas plasma. Papp, and his subsequent followers such as Rohner, Klostermann, Weber and others, claimed that they could deliver energy via a conventional piston engine using hydrogen, inert gases, electrical discharges and possibly electromagnetic resonance.

- Since the beginning of the 1990s, Erik Lerner, a plasma physicist in the USA, has claimed that it is possible to construct a cheap electricity production facility by magnetically compressing protons and the element, boron, in order directly to generate electricity from the helium nuclei so formed. He gives his apparatus the name of the Dense Plasma Focus (DPF) Machine. Experiments have been performed in Chile and elsewhere, and market agents are also active. The research is funded by private sources.

- In 1989, Fleischmann and Pons described how they had succeeded in creating “cold fusion”, using palladium electrodes in a heavy hydrogen electrolyte. However, it has been difficult to reproduce their experiment, with the result that cold fusion cooled down further.

What common thread links these attempts? This thread can be seen as them possibly being different examples of LENR technology or variants thereof. Scientific validations are now in progress in a number of places in order to confirm the functions, manage the engineering aspects and obtain an understanding of the physical mechanisms behind the processes.

Chapter 2 describes some of the model explanations that have been put forward for LENR technology, and give an indication of in what research areas advances might be expected.

Chapter 3 describes how far the validations have come (i.e. of those processes for which commercialization is planned in the near future), and who has validated what. Skeptics claim that much of the material is actually untrue. The inventors are trying to conceal their secrets in order to prevent the knowledge from becoming generally available before they have put their products on the market. Patents that have been taken out omit the most important features of the explanations.

Chapter 4 discusses various applications, based mainly on the nickel/hydrogen-based LENR technical discoveries. What would be the result of successful demonstrations and test operation?

Chapter 5 is concerned specifically with the aspects that could affect the electrical power industry. What would be the consequence of small, cheap heat/electricity production devices?

Chapter 6 discusses some of the more general conclusions drawn by the authors concerning current development work and the present status of validations.

Chapters 7 and 8 include a number of references that have not been given in the main body of the report.

Innehåll

1	Introduction	1
1.1	A new form of energy conversion?	1
1.2	How it all started	2
1.3	Controversial research	3
2	The current status of LENR knowledge	4
2.1	What is LENR technology?	4
2.2	What are the explanatory models?	6
2.2.1	Explanatory models involving ball lightning and other plasmoids	6
2.2.2	Some explanatory models based on ultra-cold neutrons	7
2.2.3	Other explanations of low-energy fusion	8
2.2.4	Rydberg matter and Bose-Einstein condensate as elements in nuclear reactions.....	9
2.2.5	Hidetsugu Ikegami's hypothesis on pycnonuclear fusion.....	10
2.3	How much is being invested in LENR investigation?	11
2.3.1	R&D in academia and by public authorities	12
2.3.2	Commercial R&D	12
2.4	Current research in the LENR field	13
2.4.1	The independence of practical trials	13
2.5	Research in the EU	14
2.6	The road to commercialisation.....	15
2.7	Applications of interest	16
3	Validated energy plants	18
3.1	Validated plasma apparatus	18
3.2	"Validated" nickel/hydrogen LENR plants.....	18
3.2.1	E-Cat, Leonardo Corporation	19
3.2.2	Hyperion, Defkalion Green Technologies	20
3.2.3	BEC Brillouin Boiler™, Brillouin Corporation	21
3.2.4	The CIHT cell, BlackLight Power.....	22
3.2.5	NANOR™, Jet Energy	23
4	Possible applications of LENR technology	25
4.1	Electricity and heat production	25
4.2	Automotive applications	25
4.3	Aviation and space applications	26
4.4	Transmutation of radioactive waste	27
4.5	Consumer products.....	27
5	Questions for the electricity industry	29
5.1	Market scenarios	30
5.2	Environmental and safety aspects.....	30
5.2.1	Unknown negative properties	32
5.2.2	Safety aspects	32
6	Conclusions	33
6.1	What is the current status of LENR research?	33
6.2	Where are the explanations?	33
6.3	Where are the greatest challenges?.....	34

7	References	35
7.1	Articles, reports and minutes	35
7.2	Web sites	38
8	Appendices	41
8.1	Patents	41
8.1.1	USA	41
8.1.2	Asia	42
8.1.3	Europé	42

1 Introduction

Could it be possible to construct apparatus that is cheap, safe and produces heat and electricity at a fraction of present-day costs? Could such apparatus be used for stationary and/or mobile applications? Would it be safe and sustainable?

This report provides an overview description of a small number of such technologies which, in one way or another, can be classified within the low-energy nuclear reactions (LENR) sphere. However, serious questions arise, as much of that described on the following pages has not yet been validated and accepted by the scientific world. Nevertheless, the question now arises as to whether, despite everything, new knowledge is being garnered that can perhaps support the results of research into low-energy nuclear reactions. The consequences of any breakthrough could be significant.

1.1 A new form of energy conversion?

It was the breakthrough of quantum physics at the beginning of the 20th century that resulted in the development of present-day nuclear power technology. Over the last 70 years, we have learnt to control many nuclear fission processes, both technically and commercially, and have now reached the stage of attempting to develop fusion technology, not least in the form of the ITER project.

At the same time, work has been in progress in many parts of the world on developing LENR technology. This is a working area that is regarded with deep skepticism by many, and is in principle impossible to realise, and even more impossible to explain, using present-day knowledge. Development has been driven primarily by experimentalists and entrepreneurs. Knowledge of what has been achieved has not spread through the normal academic circles, but often via other media. Inventors have often been put up against established scientists, and LENR technology has more than once been branded as downright deception or wishful thinking. Nevertheless, some of the results that have been published cannot simply be ignored. Nuclear reactions can apparently occur in specific environments that we do not yet understand. The laws of nuclear physics naturally apply in these environments as well as in others.

23rd March 1989 was the date when Martin Fleischmann and Stanley Pons presented their sensational discovery that energy could be extracted from a heavy hydrogen electrolyte using palladium electrodes. Neutrons were stated as playing an important part. The name of “Cold Fusion” was given to the process, and many established groups of researchers fell upon the subject in

order to repeat and verify the experiment. Very few of them succeeded in doing so at the time, and interest in the subject gradually faded.

Today, in 2013, experiments are in progress aimed at commercial development of the LENR field. One example of this work is represented by Andrea Rossi, with his E-Cat energy catalyser. At the end of the 1980s, Don Borghi, a scientist at the University of Turin in Italy, performed simple experiments using nickel and hydrogen. 1993 saw publication of a report describing experiments that had been carried out at CEN Laboratories in Recife in Brazil, based on Don Borghi's experiments, and claiming that neutrons, substantial energy evolution and other effects had been observed.¹

Other experiments at round about the same time, and investigating the nickel/hydrogen process, were claimed on several occasions to have caused explosions of such a magnitude that could not be explained by the small quantity of hydrogen in the experiment. The question is therefore whether energy was being released in some way other than from the chemically bound energy of the hydrogen.

1.2 How it all started

We go back to the middle of the 1980s, when certain spectacular experiments were carried out in the USA and documented in various ways.

Joseph Papp performed experiments based on the use of a conventional combustion engine. The cylinder space in the engine was modified and, instead of petrol, the engine was supplied with a inert-gas mixture of helium, argon, krypton and xenon. The resulting machine was given the name of "The Noble Gas Engine", with the name referring to the inert gases. Papp and his co-workers (including John Rohner) were able to show that the machine (which is well-documented in its patent) was capable of running without any additional fuel for about three months. The engine delivered a continuous power output of about 40-50 kW: sometimes outputs of 100-200 hp were obtained during the months while the engine was being tested. This spectacular experiment was questioned by the scientific world.

After Papps' death in 1989, development was continued by his assistant, John Rohner, leading to what was called the Plasmic Transmission Machine.²

In about 1985, Dr Eric Lerner, a plasma scientist in the USA, put forward a proposal for what was called a Dense Plasma Focus Machine (DPF)³. Its

¹ C. Borghi, C. Giori, A.A. Dall'Olio, *Experimental Evidence of Emission of Neutrons from Cold Hydrogen Plasma?*, American Institute of Physics (Phys. At. Nucl.), vol 56, no 7, 1993.

² http://peswiki.com/energy/PowerPedia:Joseph_Papp%27s_Noble_Gas_Engine (2013-10-15)

³ Lerner E., *Magnetic self-compression in laboratory plasmas, quasars and radio galaxies*, Part I, Laser and Particle Beams (1986) vol 4, part 2; pp 193-213.

working principle was based on the acceleration of protons, magnetic compression and bombardment of boron atoms in a relatively small confined volume. However, the DPF technology was only partially validated. Nevertheless, it was interesting that Lerner's idea came from astrophysical observations of how galaxies rotate and form energy, and that the apparatus was claimed to generate electricity directly.

1.3 Controversial research

The LENR phenomenon is stated to have many properties that are similar to superconductivity and superfluidity. These phenomena result from a collective behaviour of elementary particles, appearing themselves as quasiparticles such as phonons, plasmons and polaritons.

Many of the hypothetical explanations of LENR include quasiparticles such as phonons, polaritons and plasmons. Plasma phenomena can also play a part in some of the processes, with electrical and magnetic fields being linked by non-linearities by means of plasma resonances. Neutrons can be formed via various hypothetical models. It must be emphasised that, regardless of which phenomena that occur, they must give rise to nuclear reactions in order to release kinetic energy.

2 The current status of LENR knowledge

'Cold fusion' became a hot subject in the spring of 1989. Martin Fleischmann and Stanley Pons were thrust into the limelight on 23rd March of that year with their claim that they had experimentally shown that slow neutrons could be produced using palladium electrodes in a heavy hydrogen electrolyte. But their experiments have been questioned, and are difficult to repeat. However, in recent years, interest in 'cold fusion' – or LENR, as it is now called – seems to have increased. By the end of 2012, about 1700 articles on the subject had been published.

2.1 What is LENR technology?

Up to now, no validated theory or explanation to support low-energy nuclear reactions has been put forward. One reason for this might simply be that LENR cannot occur. Other reasons might be:

- LENR experiments have been performed in different, and non-repeatable, ways (which conflicts with the practice of performing the same experiments at several different laboratories in order to eliminate measurement errors etc.)
- The phenomenon is highly non-linear. One and the same experimental set-up is sometimes said to have delivered an energy yield, and at other times, nothing.
- Or perhaps something completely different is going on.

Trial and error work has provided some knowledge of the conditions needed to deliver an energy yield from processes that are described by some as LENR. However, no distinct rigorous evaluations of these experiments have been performed. The results from various experiments using apparatus claimed to work in accordance with LENR technology indicate the following:

- They cannot be due to chemical energy alone, as the reported energy yield is several orders of magnitude greater than can be obtained from chemical bonds.
- The energy cannot be being produced by the known form of nuclear energy, as there is no radionuclide residue, and nor have any fast neutrons or gamma radiation been detected. Both fission, as we know from present-day nuclear power stations, and thermonuclear fusion, which we know from the sun, can be ruled out. What we do know is that very special conditions, in respect of metals on a nanoscale, are needed for the reaction. What the exact role of the metal is unknown.

In other words, all this says that belief in LENR is controversial and, in some circles, viewed extremely critically. However, there are reports that claim that, as long ago as during the early 1900s, scientists might have observed or produced LENR effects⁴. The Swedish physicist John Tandberg claimed, for example, in 1927 that he had succeeded in fusing hydrogen under pressure into lithium in an electrolytic cell with palladium electrodes, but he failed to obtain the patent that he had sought.

When Martin Fleischmann and Stanley Pons performed their cold fusion experiments, they used palladium and deuterium in an electrolytic environment. The earliest LENR experiments continued with palladium and deuterium in an electrolytic cell: other tested variants used other catalytic materials. Very few successful results were reported, and then only in a few experiments. At that time, the LENR effect was not replicable.

Gradually, other metals were found to exhibit the same phenomena as did hydrogen and palladium⁵. LENR processes have also been developed in a dry environment, using hydrogen adsorbed in a gaseous state in a metal.

The combination of nickel and hydrogen was first applied by Professor Francesco Piantelli. Since then, several other academics, such as the Italian professors Sergio Focardi and Francesco Celani, and the American professor George Miley, have researched the behavior of nickel and hydrogen in the presence of nanomaterials.

If we assume that the LENR phenomenon does exist, it is the nickel/hydrogen LENR process that is probably closest to commercialization for energy applications. Against this background, this report is concerned primarily with validation of nickel/hydrogen reactors, with the addition of other information that can be of interest for further study of LENR technology from the point of view of the energy industry. Knowledge of LENR technology on the part of manufacturers is not at arm's length (see Chapter 3 on validations). The only validation that has been performed by independent scientists is that by scientists from the University of Bologna, together with Swedish scientists from Uppsala University and the Royal Institute of Technology in Stockholm. But that was concerned only with energy yield: many questions from an industrial point of view have been left unanswered, as has the matter of an accepted theoretical explanation of the entire process.

It ought to be of considerable interest to those active in the energy market to develop and commercialize LENR technology. This would open up new

⁴ Friedrich Paneth and Kurt Peters, *Über die Verwandlung von Wasserstoff in Helium*, Naturwissenschaften 14 (43): 956–962 - an article that was later withdrawn.

⁵ See F. Celani's presentation at the CERN Colloquium on 22 March 2012, <http://indico.cern.ch/getFile.py/access?resId=3 & materialId=slides & confId=177379>, where other presentations can be found at <http://indico.cern.ch/conferenceDisplay.py?confId=177379>.

business opportunities and, at the same time, challenge the existing structure of the energy system. Another important point is that of the time perspective for those systems claimed to be close to commercialization, as energy system investments have long lead times for planning, commissioning and lifetime depreciation. The fact that the technology seems to be downwardly scalable makes it of particular interest for distributed electricity production applications. Provided that LENR technology can be developed, it could be of utmost importance in an energy and climate perspective.

2.2 What are the explanatory models?

It has been speculated that LENR phenomena can occur under a wide range of conditions, which also means that there must be an equally wide range of explanations for them. In many cases, there is a lack of scientific stringency, while for others there are simply no explanations at all. To provide a picture of how different scientists, inventors and innovators see the area, the following pages present a sample of the hypothetical explanations that at present thrive. The selection is the authors' own. If '*new physics*' are needed, they are concerned with phenomena that can occur under special conditions: fundamental physics cannot be changed.

The models described below have not been chosen solely at random. They represent some models that, in one way or another, could perhaps support each other through logical relationships or possible chains of cause and effect. A criticism of some of the model approaches is that they strive against established principles. Some other theoretical explanations are based on the assumption that the standard model for elementary particles is not adequate, which flies in the face of the established scientific view⁶.

2.2.1 Explanatory models involving ball lightning and other plasmoids

Ball lightning has long been a source of fascination for mankind. How is a glowing sphere formed, and how can it pass through solid materials such as walls etc.? How did Joseph Papp's 'Noble gas engine', and other later plasma machines, work?

Clint Seward, of Electron Power Systems in the USA, has described how these plasmoids (ball lightning) might be formed in nature by an initial lightning strike⁷. The associated magnetic field captures the electrons and traps them in closed rings, which in turn create a circulating current that is self-sustaining. (Field and current directions, as well as time derivatives, obey Maxwell's laws.)

⁶ E.g. Einstein-Cartan-Evans, ECE, the theory, see
<http://drmyronevans.files.wordpress.com/2013/10/paper230.pdf>

⁷ Seward, C et al., Ball lightning explained as a stable plasma toroid,
<http://www.electronpowersystems.com>

Other workers, such as Sanduloviciu⁸, have shown experimentally a very unusual phenomenon that occurs in a plasma context. This is something that only man can perform in nature: to reduce the entropy in a system. The plasma has, in other words, an ability to organize itself to create a system that does not exhibit increased disorder if it is released, but instead creates order out of chaos. It is interesting to note the ability of the plasmoid to create a negative (dynamic) resistance, which would mean that, if so, a plasma could become superconducting. (Is this something that perhaps can explain the extremely high magnetic fields that are sometimes observed in tornados?)

It is also worth mentioning that the American Defense Advanced Research Projects Agency, DARPA, is conducting R&D in the field of ball lightning aimed at "... *understanding and quantifying the interaction of electromagnetic and acoustic waves with the plasma in flames*". DARPA's programme for 2013 also includes "*Experimentally [to] attempt 3-D observations of HF-induced plasma structures and potentially determine relative HF power absorption for different altitudes, frequencies and geophysical conditions*". Joseph Papp's 'Noble Gas Engine', creates a toroid-shaped plasma, in which a noble (inert) gas is compressed, probably thereby ionising it. A high-voltage pulse creates a magnetic field, forming an electron plasma (possibly in the way that Seward describes?). Applying an electromagnetic field in the 50-350 MHz range excites the system into resonance. This is the explanation model offered for initiation of the LENR process, but it does not say anything about which nuclear processes that provide the energy.

2.2.2 Some explanatory models based on ultra-cold neutrons

One explanatory model that is fairly frequently quoted in the LENR world is that of Preparata, Widom and Larsen, also commonly known as the W-L theory⁹. Briefly, it says that:

- Supplying energy (in the form of heat or an electromagnetic field) creates what are known as surface plasmons. When made to oscillate, they (heavy electrons) interact with protons or deuterons. The theory claims that cold neutrons (with ultra-low momentum) and neutrinos are formed.

⁸ Sanduloviciu et al., Non-linear phenomena in plasma as a consequence of self-organization, Dept. of Plasma Physics, Al.I. Cuza Univ., 6600 Iasi, Romania

⁹ The W-L Theory; see, for example, <http://newenergytimes.com/v2/sr/WL/WLTheory.shtml>, and their explanation of neutron production in Y N Srivastava, A Widom, L Larsen, A primer for electro-weak induced low-energy nuclear reactions, PRAMANA – Journal of Physics, vol. 75, No. 4, October 2010, 617-637, A Widom, L Larsen, Ultra-low-momentum neutrons catalyzed nuclear reactions on metallic hydride surfaces, European Physical Journal C – Particles and Fields, vol. 46, No 1, April 2006, 107-112, and A. Widom, J. Swain, Y.N. Srivastava, Weak Interaction Neutron Production Rates in Fully Ionized Plasmas, <http://arXiv:1305.4899v1> [hep-ph] 19 May 2013.

The cold neutrinos transmute surrounding elements, hydrogen and (for example) nickel, which then form new (unstable or stable) isotopes plus electrons and anti-neutrons. Alpha particles (i.e. helium nuclei) are formed from the hydrogen. The theory's supporters claim that electron capture in protons and neutrons occurs when the plasmons are in a high energy state, i.e. inversed beta decay.

- The created unstable heavier nuclides decay in their turn. The radiation is absorbed in the material and is said to be converted into heat. The quantity of energy released is sufficient to maintain the reaction and produce a surplus, which can be extracted as heat or electricity. Any gamma radiation formed as a result of certain transmutations is converted into IR photons (i.e. thermal radiation) by the surface plasmons. Some soft x-rays may also escape.

It can be pointed out that one of NASA's scientists, Joseph Zawodny, was granted a patent on a method of producing heavy electrons (US patent no. 20110255645A1) by stimulated resonance of surface plasmons / polaritons on electrically conducting surfaces.

2.2.3 Other explanations of low-energy fusion

Hanno Essén, at the Royal Institute of Technology in Stockholm, has proposed the following idea / model as a possible explanation for low-energy nuclear reactions, with particular focus on Rossi-type reactions of nickel powder and hydrogen:

- All materials emit electrons when they are heated. A metal powder will therefore contain an electron plasma in the space between the metal particles, with the density increasing with the temperature. Such a system will be strongly polarized: particularly so in the case of nickel, which is well known for its ability to resolve H₂ molecules into individual atoms.
- It is known that plasma can collapse if its density exceeds a certain limit, known as the Greenwald limit¹⁰. Zuin¹¹ et al. have recently reported that this occurs when the magnetic field energy density approaches parity with the rest mass energy density of the electron. In his paper¹², Essén states that this means that the magnetic field energy substantially exceeds the electric field energy.

In this plasma, which is therefore dominated by very high energy density, 'filamentation' will occur¹³ in the form of spontaneous thread-like filaments of

¹⁰ M. Greenwald, Density limits in toroidal plasmas, Plasma Phys. Control Fusion 44 (2002) R27-R80

¹¹ M. Zuin et al., A first principles explanation for the density limit in magnetized plasmas, arXiv:1001.4480 [physics.plasma-ph] (2010).

¹² H. Essén, Classical diamagnetism, magnetic interaction energies and repulsive forces in magnetized plasmas, Europhysics Letters (EPL) 94, (2011) pp. 47003-1-5

¹³ <http://www.plasma-universe.com>

current paths and magnetic fields. (Perhaps similar to solar flares?) These filaments divide and branch, and it should be possible to observe electrons that escape from them – electrons that possibly could have relativistic velocities.

- Fast electrons and filaments normally produce a pinch, due to compression of the current filament. If the electrons are sufficiently fast, this means that the charged particles that are present break the Coulomb barrier¹⁴. As the Coulomb barrier is the most difficult problem in fusion plasma physics (and normally requires temperatures of millions of degrees), this mechanism can be of particularly high interest. A pinch in a hot fusion plasma is not stable. Is it possible that random pinches are occurring in the metal powder plasma, forming and disappearing in a random manner, but in sufficient quantity to enable the occasional fusion to occur?

If so, the pinch is producing such high electron densities in its core that either the Coulomb barrier is being breached, to permit fusion between proton and/or protons and atomic nuclei, or that some other transmutation process is occurring¹⁵.

2.2.4 Rydberg matter and Bose-Einstein condensate as elements in nuclear reactions

Several theories have been advanced that consider the conditions that would enable quantum tunnelling through the Coulomb barrier to occur.

Energy impulses of oscillating nanoplasma (plasmons) or mechanical oscillation (phonons) compress the hydrogen to a super-dense state, in which ionised materials can condense to the Rydberg state¹⁶. It is presumed that the dipole moment creates an electric field (plexitrons) that catalyses fusion of the hydrogen or deuterium nuclei at the correct frequency by tunneling through the Coulomb barrier.

The Shukla-Eliasson effect means that a new electric potential is created, screened by degenerated electrons, related to Bohm's quantum potential and to other properties of electron correlations. Through this negatively charged potential, it is possible for positively charged particles and ions to combine in atomic structures in the nano-plasma, both at critical points and at phase transitions in the nano-plasma¹⁷.

¹⁴ H. Essén, The exact Darwin Lagrangian, Europhysics Letters (EPL) 79, (2007) pp. 60002-1-3

¹⁵ H. Essén, Catalyzing Fusion with Relativistic Electrons, arXiv:physics/0607138v1 [physics.plasm-ph], July 2006

¹⁶ Hydrogen in the Rydberg state is described (for example) in Leif Holmlid, Largeion-cluster HN+ of Rydberg Matter: Stacks of planar cluster H7, International Journal of Mass Spectrometry, Vol. 300, Issue 1, 30 January 2011, pp. 50-58. Rydberg matter is also considered as an explanation in Pekka Soininen's LENR invention, described in patent application WO2013076378 A2.

¹⁷ P. K. Shukla, B. Eliasson, Novel attractive force between ions in quantum plasmas, Phys. Rev. Lett. 108, 165007 (2012); Erratum: PRL 108, 219902(E) (2012); PRL 109, 019901 (E) (2012)

Defkalion's Hyperion reactor is explained by hydrogen molecules being ionised to the excited hydrogen state, which includes Rydberg matter atoms. The hydrogen is assumed to resolve into protons and electrons, with acceleration of the charged particles creating a magnetic field. The manufacturer has measured peak magnetic field strengths of 1,6 T, persisting for some seconds after each high-voltage pulse. It is assumed that a superconducting Bose-Einstein condensate of protons, accelerated by the high-voltage pulses, is initiating the process¹⁸. The protons are thought to form pairs which interact in integer spin, which forms boson clusters. In what is known as a Bosenova (a very small, supernova-like explosion), deuteron-deuteron reactions occur that form He-4. This is done with nano-explosions. The residual material, consisting of several different nuclides, indicates that the high energy density can in turn give rise to fission processes.

2.2.5 Hidetsugu Ikegami's hypothesis on pycnonuclear¹⁹ fusion

As opposed to the thermonuclear process, which occurs in the sun, there is also a pressure-based fusion process, known as pycnonuclear fusion. Astrophysicists have shown that fusion reactions can be observed in ultra-dense materials at temperatures approaching absolute zero. These pycnonuclear reactions, where explosive chain reactions from the fusions are possible, have also been observed in laboratories²⁰.

Neutron production has also been reported in the experiments exposing lithium to proton beams, performed under the leadership of Professor Hidetsugu Ikegami of the University of Osaka. The results of the cooperation between the Universities of Uppsala and Osaka are documented in a number of reports over the period 2002 – 2006. The experiments resulted in an energy yield that could not be explained by ordinary thermonuclear fusion. these are the known experimental trials in the LENR field in Sweden that are described in the paper '*Ultradense Nuclear Fusion in Metallic Lithium Liquid*'²¹.

In his descriptive model of pycnonuclear fusion, as described in '*The Nature of the Chemonuclear Transition*'²², Professor Ikegami explains how chemonuclear fusion is a pycnonuclear fusion process, as is known from astrophysics.

¹⁸ Yeong E. Kim, John Hadjichristos, Theoretical Analysis and Reaction Mechanisms for Experimental Results of Hydrogen-Nickel Systems, Purdue Nuclear and Many-Body Theory Group (PNMBTG) Preprint-PNMBTG-10-2013(October 2013). Invited paper presented at ICCF-18, University of Missouri, July 21-27, 2013

¹⁹ Pycno = dense.

²⁰ S. Son, N.J. Fisch, Pycnonuclear reaction and possible chain reactions in an ultra-dense DT plasma, Physics Letters A 337 (2005) 397–407

²¹ H. Ikegami, T. Watanabe, R. Pettersson and K. Fransson, Ultra-dense Nuclear Fusion in Metallic Lithium Liquid. A report on research performed at the R&D Center, Sakaguchi E.H VOC Co. under the auspices of the Swedish Energy Agency, ER 2006:42

²² H. Ikegami, The Nature of the Chemonuclear Transition, TSL note, Uppsala 2012

Deuterons with keV energy levels penetrate the lithium atoms' s-orbital electron cloud, to form intermediate LiD atoms. At this energy level, it is the nuclear collisions that dominate over the electronic collisions in the moderating process. The energy of the deuterons is sufficient to compress the molecule to about 7 % of its original volume (*from which comes the 'pycno' prefix, meaning 'dense'*). This means a formation of both nuclei at a distance apart of less than 1 pm inside the now shared K- and L- electron shells. The fused atomic state undergoes an adiabatic transition to a nuclear fusion reaction, with a certain probability as determined by the Gamow factor, i.e. the probability of two atom nuclei's ability to overcome the Coulomb barrier in order to undergo a nuclear reaction.

In the framework of classical thermodynamics, the process can be regarded as that of chemical reactions in dilute solutions, to which Arrhenius' equation for spontaneous chemical reactions applies. This defines the speed of a chemical reaction at a given temperature by starting from the activation energy and probability of successful collisions between the molecules. The change in Gibbs' energy in the exponent of the amplification factor is negative in the case concerned, i.e. of the reaction between deuterons and lithium to form LiD. Consequently, an amplification of $e^{(-\Delta G/kT)}$, with many orders of magnitude of nuclear fusion reactions in the metallic lithium liquid, is achieved.

It is easy to be side-tracked into difficult-to-understand scientific reasoning, involving quantum physics, plasma physics, quantum electro-dynamics etc. The above reasoning is intended only to describe some hypothetical mechanisms with which the theoreticians are working. Those performing the experiments are perhaps somewhat less concerned with the theories, as long as processes and results are moving in the right direction, and the explosions are controllable.

Summarising, it can be said that, among all the explanatory models flourishing around the LENR phenomenon, it may be that this is the same phenomenon, manifesting itself in different ways, or that we are seeing different phenomena manifesting themselves in different ways. However, it is also perfectly possible that certain common characteristics can be distinguished, and these will be discussed later in this report. Nevertheless, Professor Ikegami's model does explain how nuclear reactions occur, even though the path to that explanation is beset by unclear points.

2.3 How much is being invested in LENR investigation?

It is difficult to estimate how much is being spent on LENR as, apart from a few exceptions, no official figures are released. The following points are therefore simply examples.

2.3.1 R&D in academia and by public authorities

One university that has an LENR programme is the University of Missouri, which has established the Sidney Kimmel Se bild 5 av Y. Kim och J. Hadjichristos på <https://mospace.umsystem.edu/xmlui/handle/10355/36783> 2013-08-12 Institute for Nuclear Renaissance (SKINR) with a donation of USD 5,5 million from the philanthropist Sidney Kimmel. The Institute was opened in April 2012, as a department within the School of Physics and Astronomy at the university, reporting directly to the Vice-Chancellor for Research, Dr. Robert V. Duncan²³.

One example of R&D funding is that provided by DARPA (US Department of Defense) in its budget for military research in 2013 and 2014. The *Fundamentals of Nanoscale and Emergent Effects and Engineered Devices* working area, for example, has a budget of USD 5,159 million for 2013, and USD 6,5 million for 2014. The programme plan states, for example, that the programme “... seeks to understand and exploit physical phenomena for developing more efficient and powerful devices. This includes developing devices and structures to enable controllable photonic devices at multiple wavelengths, engineering palladium microstructures with large deuterium loadings to study absorption thermodynamics and effects, and enabling real-time detection as well as analysis of signals and molecules and origin of emergent behavior in correlated electron devices”.

2.3.2 Commercial R&D

An example of R&D funding in a manufacturing company is that of the Brillouin Energy Corporation. The company has been allocated USD 20 million capital for a ‘second stage’ of a conditional contract with Sunrise Securities of New York, NY (www.sunrisecorp.com)²⁴.

- The Sunrise offer would purchase 15% of BEC post-money, conditional upon BEC moving ahead with, and completing successful testing of, its NHB™ at SRI.
- The Sunrise offer is also conditional on Brillouin reaching preliminary agreement to acquire at least one “stranded asset” conventional fuel source small-scale (5-10 MW) power plant, with existing conventional cogeneration equipment, and replacing (retrofitting) the old fuel source with Brillouin’s hot tube NHB™, together with renewal of an operating power purchase or steam heat contract with an industry or a utility.
- Key expert affiliates of Sunrise, including former Director of the California Public Utilities Commission (CPUC)’s independent power division, have already provided potential acquisition candidates, available for negligible cost, with power contracts already in place.
- Upon successful testing of NHB™ at SRI, the \$20M Sunrise offer will fund full commercial launch of this merchant power supply retrofit business model.

²³ http://iccf18.research.missouri.edu/files/day2/SKINR_Overview.pdf

²⁴ <http://www.slideshare.net/ssusereef70/brillouin-bus-sum4512>

2.4 Current research in the LENR field

Today, there are over a thousand peer-reviewed articles on LENR, with some estimates going up to 1700 articles. Many of them can be read on <http://lenr-canr.org>. Most of them describe the use of palladium and deuterium in an electrolytic environment, as this was the reaction that was described by Fleischmann and Pons in 1989. Most of the disciplines to which the workers in the field belong are electrochemistry, solid state physics, nanotechnology, analytical chemistry and quantum electrodynamics.

LENR has not been observed in the situations with which nuclear physicists are normally concerned, i.e. primarily nuclear processes with relatively fast neutrons (2000-3000 m/s). By elimination, it can be suspected that LENR is a complex physical process (perhaps including weak interaction)²⁵, and not a normal nuclear physics strong disintegration process such as fission or fusion. Transmutations occur of hydrogen into helium, and also of heavier elements in certain LENR experiments. Just how this occurs in detail is difficult to say, as in certain cases the process occurs on a 2-10 nanometer scale in crystalline materials, possibly larger, and with pulses at the right frequency or in 'dusty plasmas' or noble gas plasmas.

There are many competing explanations: it will presumably be many years before a validated explanation of the theory is found. The process of first observing the phenomenon, for which the theory cannot be explained at first, is the accepted way of acquiring transformative knowledge. However, lack of an understanding of the theory around LENR does not prevent the technology from being introduced to the market. To be approved for release on to the market, a product must have a safety certificate from an accredited approval organisation, such as Underwriters Laboratories (UL). Leonardo Corporation obtained such a safety certification for its 1 MW industrial version of E-Cat from SGS²⁶.

2.4.1 The independence of practical trials

Nevertheless, scientists have come a long way using the trial-and-error method. Process descriptions of LENR experiments, with details of materials, can be found on the Internet²⁷. One example is that of the Pirelli experiment, performed in an electrochemical environment by lecturers and students at the Leopoldo Pirelli Industrial High School in Rome, and which is described on the Internet²⁸. One of the experiments in its Athanor reactor produced a 400 %

²⁵ An example of such a complex interaction is described in J. Swain, A. Widom, Y.N. Srivastava, Electrostrong Nuclear Disintegration in Condensed Matter, <http://arXiv:1306.5165v1> [nucl-th] 19 June 2013.

²⁶ SGS Italia S.p.A., Voluntary Certificate of Compliance with Safety Requirements of Directive 2006/42/EC (Annex SGS I)

²⁷ E.g. at <http://22passi.blogspot.se/2012/04/lathanor-delliis-pirelli-di-roma-1.html>

²⁸ See the set of pictures at http://roma.repubblica.it/cronaca/2012/04/19/foto/il_reattore_costruito_dagli_studenti-33583028/1/

energy surplus. It is more difficult independently to perform experiments using the dry gas version, with nickel and hydrogen, as this requires knowledge of such areas as geometric conditions of the nickel containers, the particle size of the powder, and the amplitude and frequency of the electric pulse to start the process. In addition, it is necessary to know how to control the process so that it does not end up by exploding (which has happened many times). We therefore need more in-depth knowledge of how this commercial nickel/hydrogen process works. Of the validations of commercial processes described below, only two have been performed (as far as is known) by scientists not financed by the companies whose equipment was the subject of the validation. These two validations are of equipment from Defkalion and the Leonardo Corporation, although the validation of the Defkalion Hyperion reactor was performed by an industrial scientist in the presence of personnel from the commercial company.

MIT ran open courses in LENR technology in January 2012 and 2013²⁹. LENR equipment from Jet Energy was demonstrated on the 2012 course, and was reported as working for six months³⁰. A test from Milan was webcast to the ICCF Conference at Missouri University on 23rd July, where Defkalion publicly exhibited operation of its Hyperion reactor³¹. This should be seen as a commercial company exhibiting a product under development. A test report from the public demonstration is available³².

LENR technology validations will not be generally accepted until the apparatus has been tested by independent scientists at an independent site. In addition, there will presumably be a need for transparency concerning all the materials used and their operating parameters in order to be able to interpret the equipment's performance. General widespread acceptance will await successful demonstrations of their equipment by other LENR manufacturers. Up to now, no completely independent demonstration of all the parameters in an LENR reactor has been performed. The scientists from Bologna and Uppsala University were able to investigate only the energy yield from Leonardo Corporation's Hot-Cat reactor in December 2012 and March 2013: see the results in Section 3.2, '*Validated' nickel/hydrogen LENR plants*'.

2.5 Research in the EU

In various EU forums, ENEA (Italian National Agency for New Technologies, Energy and Sustainable Economic Development) has put forward the need to invest EU research funding in LENR. An example of this is the proposal for

²⁹ <http://student.mit.edu/searchiap/iap-BD6D0CF8E170B284E0400312852F4A61.html>, 2013-08-19

³⁰ <http://cdn.coldfusionnow.org/wp-content/uploads/2012/12/HagelsteinPdemonstra.pdf>, 2013-08-19

³¹ See the webcast on <http://new.livestream.com/triwu2/Defkalion-US>

³² Hyperion devise Functional & Performance Test Plans & Test Results, test code: 3.2.30, http://iccf18.research.missouri.edu/files/day2/Protocol_and_test_results.pdf 2013-08-19

materials research for LENR within the EU³³, and the meeting arranged by Amalia Sartori, Chairman of the European Parliament's ITRE Committee and ENEA Commissioner Giovanni Lelli on 3 June 2013³⁴. The meeting was chaired by Edit Herczog, a member of the ITRE Committee.

The meeting heard of the joint work in the field of LENR research that has been carried out since 2004 by ENEA in Italy, Stanford Research International and Energetics LLC in the USA. The American Naval Research Laboratory (NRL) joined the group in 2008, followed in 2010 by the University of Missouri. The meeting was also given presentations, by palladium/deuterium workers, of the reproducibility and actual power output of the LENR process. The participants at the meeting were electrochemist Michael McKubre (Stanford Research International, SRI), Robert Duncan (Vice Chancellor for Research, University of Missouri) and Graham Hubler (Director of the Sidney Kimmel Institute for Nuclear, University of Missouri) from the USA. From Italy came Vittorio Violante (LENR Research Coordinator, ENEA, and professor at the Università degli Studi di Roma, Tor Vergata, Rome), while German presence was in the form of Professor Konrad Czerski (professor at the Uniwersytet Szczecinski, Poland and at Technische Universität Berlin).

2.6 The road to commercialisation

A number of companies are planning to commercialise products that they claim are based on LENR technology, presumably launching them before a generally accepted explanation of the theory has been found. Market introductions are dependent on many factors, such as the functionality and degree of technical maturity of the equipment, safety, patent rights, economic aspects, environmental benefits and acceptance by politicians and the general public.

Leonardo Corporation has three types of apparatus: E-Cat, Hot-Cat (a high-temperature E-Cat) and one that is controlled by gas. The Hot-Cat version is intended to supply steam to a turbine for electricity generation. The E-Cat is a 1 MW industrial version for heat production which, according to the company, has a short manufacturing lead time of four months from order to delivery. The company is said to have supplied three units to its American owner: one E-Cat for heat supply, one E-Cat with gas control, and one Hot-Cat for electricity production. According to the company, the owner company has sold the units on to their end users (names not known).

Defkalion Green Technologies has two main routes for launching its technology: hardware for energy conversion, and licensing of its technology to manufacturers of consumer products that require energy to operate. The

³³ Johan Veiga Benesch (Ed), *Forward Looking Workshop on Materials for Emerging Energy Technologies*, EUR 25350 EN, European Union 2012

³⁴ See ENEA's website <http://www.enea.it/it/Ufficio-Bruxelles/news/new-advancements-on-the-fleischmann-pons-effect-paving-the-way-for-a-potential-new-clean-renewable-energy-source>, where the participants' presentations are available.

company claims that it has granted licenses to about 20 companies for powering various types of products. Two of these companies have been presented as one of Europe's largest automotive manufacturers and one of the world's largest mobile phone manufacturers. Hyperion is scheduled for market introduction in 2014, in sizes from 10 kW to 1 MW+, with COPs of 6-18. The equipment and instrumentation for the public demonstration at ICCF-18 in Milan in July 2013 were under Defkalion's full control. Unfortunately, due to problems of de-gassing the reactor, which was stated to be sensitive to small quantities of gases other than hydrogen, the reactor delivered a COP of only 2,0. However, this did not allow for the latent heat of evaporation of the steam: doing so would have given a considerably higher COP.

Brillouin Corporation's apparatus is known as the BEC Brillouin Boiler™. The company has received USD 20 million in venture capital from Sunrise Securities Corporation in New York City to equip a coal-fired power station with an LENR-powered boiler in the 5-10 MW range³⁵. The agreement includes nickel expertise in contact with Sunrise, for which company a former director of the independent power division of California Public Utilities Commission (CPUC) has already offered potential acquisition candidates, available for minimal costs, with existing electricity contracts. It is not known when Brillouin will have a reactor developed and available for industrial use.

BlackLight Power's technology is a wet electrolytic cell, using hydrogen from water vapour as the energy source. This is said to be able to generate electricity directly without any intermediate heat generation. The company also has a dry process, suitable for heat production and steam for electricity generation. Here, too, plans for market launches are not known.

Jet Energy's NANOR™ apparatus, designed by Mitchell R. Swartz, is at present at the demonstration stage.

LENUCO, with a reactor having a present-day output of 100-300 W, is planning to produce commercial-scale models with outputs of 3 kW to 30 kW in 2013/14. The company's owner, George H. Miley, holds the first American LENR patent, no. US 8 227 020, issued on 24th July 2012.

NicHEnergy, an R&D company started by Francesco Piantelli, has a reactor that today generates 10-100 W. **Metalenergy** is a sister company that plans to commercialise the technology.

2.7 Applications of interest

If LENR technology works and is repeatable, controllable and scaleable, there is a range of applications where it could be used. As it is not possible at present to say anything about the costs of (large-scale) commercial plants

³⁵ See Page 14 in the presentation; <http://www.slideshare.net/ssusereef70/brillouin-ppt-technical32712>

that might be built, we must resort to a coarse hypothetical approach. As far as investment costs are concerned, we can assume that the manufacturers will apply market prices for their equipment, but at levels that are very competitive in comparison with established energy sources. However, costs for the actual material of the reactors, together with hydrogen and nickel, are low. Based on nickel/hydrogen processes, operating costs amount mainly to the cost of powdered nickel and hydrogen/deuterium. However, the various designs that could be considered probably have different ways of managing fuel reloading etc. The first reactor charge will probably also differ, depending on the application. A stationary power station can have a greater volume and longer duty cycles than, say, a vehicle.

3 Validated energy plants

As many experiments have been carried out over a long period of time, but only recently have started to be classified as LENRs, we have chosen to describe validation of some energy plants that can be classified as being based on unknown phenomena, but which could have a link to possible nuclear processes. We also discuss some of the initial experiments having a pure plasma physics background, as well as those relating to later experiments, all gathered under the umbrella name of LENR technology.

3.1 Validated plasma apparatus

One of the machines that is documented, and also partly officially validated, is Joseph Papp's 'Noble Gas Engine'. Papp worked with Robert and Tom Rohner during the 1970s and 1980s. 'The Rohner Group' has since continued working on Papp's machine, with some videos being available³⁶.

For the scientific validation, which was performed at CalTech by Richard Feymann and others, Papp worked with Jimmy Sabori and Rohner brothers, Tom and Robert. The results of the validation were at least discussion-rousing, as the machine exploded. Development of the machine continued after Papp's death in 1998, producing a number of variants on the original machine. It is unclear whether these machines were validated. John Rohner obtained a patent for a 'Plasmic Transition Process Motor' (US20110113772A1) on 18th November 2009.

In due course, Heinz Klostermann entered the picture and, in 2006, was granted a patent (US7076950B2) in his name. Several different development companies have been involved, but it is unclear as to whether any significant results have been produced. A plasma machine, fairly similar to Rohner's later models, and based on a nickel piston working in a hydrogen environment, appeared in a German patent (DE102011103832A1) granted to Jürgen Weber in December 2012. It is not clear as to whether this has been built or not. What is clear from the patent is that the hydrogen must be heated to a temperature in the range 150-500 °C.

3.2 "Validated" nickel/hydrogen LENR plants

In our review, we have found eight "overviews" of the actual LENR process as such. One of these was produced by Edmund Storms, and published in *Naturwissenschaften* in 2010³⁷. In addition to these process validations, a number of other validations have been performed for commercialisation of

³⁶ <http://pappengine.com/videos.htm>

³⁷ Edmund Storms, *Status of cold fusion*, *Naturwissenschaften* October 2010, Volume 97, Issue 10, pp 861-881.

more or less developed plants, which are those that are described below. Validation of energy generation in the following reports is based on the equipment's Coefficient Of Performance (COP), which is the ratio between the usable output energy and the energy inputs supplied to the machine.

3.2.1 E-Cat, Leonardo Corporation

The Leonardo Corporation quotes several public validations of its LENR apparatus, although only one of them (the last one) has been performed by an independent third party. The various apparatuses are described on the corporation's website³⁸.

The 1 MW industrial E-Cat has been safety-certified by SGS Italia S.p.A. The first validation was not performed by an independent third party, but was published by the Leonardo Corporation under the name of *"Report on the internal test performed on the Hot Cat"*, dated 16th July 2012. This validation is stated as having been performed by Fabio Penon, M. Eng. in nuclear power, and a 'product specification specialist', Fulvio Fabiani, M.Eng., and David Bianchini, M.Sc. in physics and a radiation measurements specialist. The test lasted for 6,48 hours, with a mean power density between 58 and 117 kW/kg, and an energy density of between 378 and 758 kWh/kg. The report does not calculate the COP, but states that the released energy cannot have come from chemical reactions.

The next report from the Leonardo Corporation is dated 9th October 2012, and describes the results of testing performed by Fabio Penon. The reactor was monitored in self-sustaining mode over a period of 118 hours. The power density was calculated as 163,4 MW/kg, from an input energy of 278,4 kWh which, with an energy production of 3357 kWh, gives a COP of 11.7. The Leonardo Corporation's own Hot Cat tests have been questioned in respect of the metering of electric power to the process. However, when the process is operating in self-sustaining mode, this argument does not apply.

The validation that was carried out by independent scientists over the period 13-17 December 2012 related to the energy yield, and was performed by Giuseppe Levi, University of Bologna and Evelyn Foschi, Bologna. The 18-23 March 2013 validation was performed by Giuseppe Levi, University of Bologna, Evelyn Foschi, Bologna, Torbjörn Hartman, Bo Höistad, Roland Pettersson and Lars Tegnér, of Uppsala University, with Hanno Essén, the Royal Institute of Technology, Stockholm.³⁹ The results of this validation included a high energy yield, a high energy density and no detected radiation.

³⁸ Leonardo Corporation's descriptions of products, <http://ecat.com/ecat-products/ecat-1-mw> och <http://ecat.com/ecat-products/ecat-ht-hot-cat-prototype>

³⁹ Giuseppe Levi, Bologna University, Evelyn Foschi, Bologna, Torbjörn Hartman, Bo Höistad, Roland Pettersson, Lars Tegnér, University of Uppsala and Hanno Essén, KTH, *Indication of anomalous heat energy production in a reactor device*, arxiv.org/abs/1305.3913v3

The validation showed that energy from the Hot-Cat could not be only chemical energy. It must be pointed out, however, that due to commercial considerations the validation scientists were not given access to all the data. For this reason, the scientific community is critical of performance of the test.

The first test:

The equipment was operated with an energy consumption of 35 kWh, generating a net output of 160 kWh. Heat, in the form of convection and radiation from a Hot Cat, was calculated. The results gave a power density of 7 kW/kg and an energy density of 680 kWh/kg, indicating that a Hot-Cat produces more energy than do conventional energy sources. The COP of the test was $5,6 \pm 0,8$.

The second test:

The equipment was operated with an input of 33 kWh, delivering a net output of 62 kWh. The calculated power density was 530 kW/kg, and the energy density $61 \cdot 10^3$ kWh/kg. The COP of the test was $2,6 \pm 0,5$.

In both these test cases, the reactor was stopped deliberately, and not as a result of fuel consumption. This means that calculated energy densities must be regarded as lower than what the real values would be. With conservative assumptions, the Hot Cat that the scientists validated had an energy density of about 100 000 times that of petrol, and a power density of about 1000 times that of petrol.

Forbes has published a Ragon diagram in which the Bologna results are plotted: see:

<http://www.forbes.com/sites/markgibbs/2013/05/20/finally-independent-testing-of-rossis-e-cat-cold-fusion-device-maybe-the-world-will-change-after-all/>

3.2.2 Hyperion, Defkalion Green Technologies

Defkalion Green Technologies' Hyperion reactor was tested by Michael A. Nelson, an independent energy consultant with a record of 30 years as a NASA employee. He performed the test, not in his capacity of a NASA employee, but as a representative of the New Energy Foundation (a non-profit organisation, founded in 2002 and based in New Hampshire), which also paid for the test. Hyperion has also been demonstrated to the Greek government.

Michael Nelson's test summary, published on 18th October 2012, states that:

- 1 The apparatus generated an energy surplus.
 - 2 Defkalion demonstrated that it could maintain full control of the reaction by starting it, stopping it, increasing it and decreasing it.
-

3 The reaction requires hydrogen.

4 The contents of the reactor were removed and weighed, amounting to 59 g, of which most was the ceramic container. The reaction delivered more energy than would be possible from a chemical reaction from the same mass, indicating that a nuclear reaction is involved.

5 There are uncertainties of measurement associated with all the data, which have not yet been resolved.

6 Defkalion is honest in its attempts, using accurate measurements and in demonstrating the performance of its technology in the belief that it can deliver a COP >1 over a sufficiently long period of time to eliminate the possibility of a chemical reaction. A preliminary assessment of the measurement data indicates that the reactor is producing a COP >3.

Defkalion's product data sheet claims:⁴⁰ "Nickel and hydrogen, electric power heating, chemical assisting preheating media not to be disclosed, max pressure 150 bar, continuous use temperature max 1100 °C, COP better than 1:25 for 5-11 kW Series A and C, better than 1:35 for 10-45 kW Series B and D."

This high value of energy yield has not yet been publicly verified. Unconfirmed reports claim that earlier tests have shown a COP>20.

3.2.3 BEC Brillouin Boiler™, Brillouin Corporation

Several scientists have stated that deuterium fusion can have occurred in certain metal hydrides. BEC states that there may be other mechanisms that release the binding energy in, for example, helium.

Many experimental results are reminiscent of those that can be linked to deuterium fusion, such as the quantity of helium that is formed, heat production etc. In addition, tritium is formed.

Deuterium fusion is quite a close fit for an explanatory hypothesis. The process produces no gamma radiation, and no fast neutrons are observed. Similarly, no energy levels are needed in order to break the Coulomb barrier. Brillouin's hypothesis includes the following elements:

- That it should be possible to operate the reaction with considerably fewer protons in the metal matrix than the 85 % or more that other groups require.
- That it should be possible to start the reaction process in milliseconds, rather than having to wait for unknown factors such as cosmic radiation.

⁴⁰ Defkalion Green Technologies, product sheet of Hyperion Series A, B, C and D , see http://aromapress.com/~defkalio/wp-content/uploads/2013/01/2011-11-30_Hyperion-Spec-Sheet.pdf

- That it should be possible to release surplus heat and produce helium by using protons instead of deuterons.
- It should be possible to operate the reaction with ordinary palladium, nickel or tungsten.
- It should be possible to increase the power output by using high-pressure or high-temperature designs.

The Brillouin Energy Corporation's apparatus, the BEC Brillouin BoilerTM, holds two validations by independent testers⁴¹. However, they have presumably been paid for by Brillouin Energy Corporation, and cannot therefore be ranked as third-party validations. One of these has been performed by Los Alamos National Laboratories, while the other was performed by Dr Michael McKubre, of Stanford Research International (SRI), who was subsequently linked to the company's advisory board.⁴²

3.2.4 The CIHT cell, BlackLight Power

BlackLight Power's continuous power production process converts ordinary water vapour (H₂O) into electricity, oxygen and a new, more stable form of hydrogen, to which the company has given the name of hydrino. According to Dr Randell Mills, Chairman, CEO and president of BlackLight Power, Inc., and discoverer of the BlackLight Power process, this releases more than 200 times more energy than that which would be released by combustion of pure hydrogen.

Dr Mills claims that BlackLight Power has reached an important milestone in scaling up the process, typically delivering a COP of more than 10 over a long period for units in the 10 W output range. The company is now said to be planning a 100 W unit, and hopes to release a 1.5 kW apparatus for domestic use during 2013.⁴³

BlackLight Power's cell has been validated over periods of 30 – 70 days' continuous operation by six different constellations of individuals and groups of scientists, regarded by the company as independent. These scientists are PhD holders from universities such as MIT and Caltech. What is not clear is from which sources the scientists receive payment for their validations, which means that the following details from six validation records cannot be regarded as true third-party validations.

⁴¹ <http://nextbigfuture.com/2012/04/brillouin-had-los-alamos-and-sri.html> 2013-08-19, picture 13 in the presentation:<http://www.slideshare.net/ssusereef70/brillouin-ppt-technical32712> and <http://episin.blogspot.se/2011/07/brillouin-energy-reactor-being-tested.html>, 2013-08-19

⁴² The board of Brillouin Energy is presented on <http://brillouinenergy.com>

⁴³ BlackLight Power's website, <http://www.blacklightpower.com>

K. V. Ramanajachary was Professor of Chemistry and Biochemistry at Rowan University. His expertise areas are the oxidation chemistry of metals, electrical and magnetic properties of materials, and ion-conducting polymers and oxides. Professor Ramanajachary found that CIHT cells had a COP of between 1,6 and 7,35.

Terry Copeland, a chemical engineer from MIT, who has worked with Duracell and other battery manufacturers, as well as at Altair Nanotechnologies Inc., performed two evaluations of CIHT cells in November and December 2011, finding COPs between 2 and 5,5.

At the time of performing his validation, Professor Henry Weinberg was Professor of Chemical Technology and Chemical Physics, as well as Professor of Materials Technology at California Institute of Technology. He has a long CV in academia, having held different professorships at a number of universities. Professor Weinberg found that the CIHT cell had a COP of 10.

One validation group consisted of a team from Fortune 500 companies, with US DOD advisors, consisting of an R&D programme director working for NASA, a PhD in physics, and a PhD in chemistry with fuel cell expertise. This group found that CIHT cells using nickel delivered a COP >2, over 5 – 27 days' operation, after stabilisation, with some values over 300. Cells using molybdenum instead of nickel returned a COP up to 2420.

Nick Glumac had been Professor of Machine Technology at the University of Illinois since August 2007. He performed his validation in the capacity of technical consultant working with Mahomet, finding energy yields from 10 and upwards. The cells using molybdenum returned a COP value of about 2000, while those using nickel delivered a value between 9.1 and 14,4 after 17 days.

Two PhDs from the ENSER Corporation have performed an evaluation. ENSER is a company that works with the American military, supplying missile batteries. 25 of its staff are engaged in electrochemical research. James K. Pugh, an expert in physical organic chemistry and electrochemistry, is ENSER's technical director. Ethirajulu Dayalan is a research colleague in the field of electrochemistry, who has worked with NASA, the US Army and others. Both these scientists found a COP of about 100 from CIHT cells.

3.2.5 NANORTM, Jet Energy

Jet Energy's NANORTM apparatus, working in the mW range, was tested at MIT for the period from January to June 2012 and also demonstrated publicly. The equipment was reported to return a COP of 12-14 over the test period.⁴⁴

⁴⁴ <http://nextbigfuture.com/2012/06/mit-lenr-device-publicly-running-for-6.html> 2013-08-19

The company's LENR reactor exhibited similar energy and power densities to those of the Leonardo Corporation's Hot Cat, which can be seen from the Ragon diagram on the company's website <http://world.std.com/~mica/cft.html>, under the heading "Why is cold fusion so important?" The graph was presented to the ICCF18 conference on 23rd July 2013.

4 Possible applications of LENR technology

4.1 Electricity and heat production

If LENR technology works as is claimed today, its most likely applications would be district heating production and heat and steam generation for industrial processes. The reason for the equipment first being released to technically-aware and technically-capable customers is to be found in safety aspects. Leonardo Corporation has a safety certificate only for its 1 MW plants, and is still in the process of applying for safety certification of smaller plants intended for domestic customers. The company expects that the private customer market will take off if experience from industrial customers is favourable. If it works, LENR equipment in the future would be capable of competing both with district heating utilities and with end-users, e.g. as an alternative to heat pumps for bio-energy.

Plants for electricity generation are also possible. An example of this is presented by the Hot Cat for electricity generation, which was tested in Bologna. Here, too, it can be expected that industrial customers' experience will provide a basis for safety certification of smaller units for the domestic customer market. In the USA, there are plans to re-invest in old coal-fired power stations by replacing their boilers with LENR reactors. In future, LENR equipment could be seen as competing not only with fossil-fuelled and nuclear power generation, but also producing electricity for both private and industrial customers. The Kresenn Company is stated to be working on the development of LENR power systems for data centers.⁴⁵

4.2 Automotive applications

If LENR technology works, an important application will be that of powering electric vehicles. Papp's original machine was based on an ordinary combustion engine: Rohner's, Klostermann's and Weber's designs are all also based on conventional mechanical technology, with pistons and flywheels, but with the combustion chamber replaced by the plasma chamber.

LENR reactors for powering vehicles are also being investigated by LENR Cars Sàrl in Lausanne.⁴⁶ The design shown on the company's website is similar to that of other LENR apparatuses, but with the difference that it is intended to deliver electricity. This could be done by thermoelectric conversion, or alternatively by using the reactor as a heat source for a Stirling engine. The company has a patent pending under the name of Low Energy Nuclear

⁴⁵ <http://www.kresenn.com/> 2013-08-19

⁴⁶ Nicolas Chauvin, *LENR Powered Electric Vehicles*, Proceedings ILENRS -12, Williamsburg, USA, July 1-3, 2012

Thermoelectric System, US 2013/0263507 A1, published on 10th October 2013.

It has been reported that Toyota and Honda are investing in LENR research, with the aim of developing LENR-powered vehicles.⁴⁷ Toyota is also working with scientists at the Universities of Osaka and Kobe.⁴⁸ If and when automotive applications are developed, they will be in competition with electric, biogas-fuelled and hybrid vehicles.

Parties interested in military transport and similar applications include SPAWAR, NRL, DARPA, DTRA and DIA, all of which have performed LENR research.⁴⁹ On 13th November 2009, DIA published its report *Technology Forecast: Worldwide Research on Low-Energy Nuclear Reactions Increasing and Gaining Acceptance*, in which it reports: "... the military potential of such high-energy-density power sources is enormous. And since the US military is the largest user of liquid fuel for transportation, LENR power sources could produce the greatest transformation of the battlefield for US forces since the transition from horsepower to gasoline power."⁵⁰

4.3 Aviation and space applications

NASA and Boeing are investigating the potentials of future LENR power generation for ecological powering of aircraft, as described in NASA's report: *NASA/CR-202-217556 Subsonic Ultra Green Aircraft Research Phase II: N+4 Advanced Concept Development*.⁵¹ An important aspect is that of how aviation might develop if the weight of fuel that aircraft will need to carry was reduced to almost zero.

For military aviation applications, it is the possibility of developing supersonic aircraft with almost unlimited range that is a particular object of research. For space applications, it is the possibility of 50 % more net load capacity in reusable cargo rockets that is attractive, together with no maintenance and the possibility of building ever smaller spacecraft. NASA is therefore investigating LENR powering of space sondes.⁵²

⁴⁷<http://coldfusiondevices.com/cold-fusion/cold-fusion-devices-to-power-cars-in-the-future>

⁴⁸<http://energycatalyzer3.com/news/toyota-is-active-in-cold-fusion-research-again>, 2012-10-01

⁴⁹ The organizations are: Space and Naval Warfare Systems Command, U.S. Naval Research Laboratory, Defense Advanced Research Projects Agency, Defense Threat Reduction Agency and Defense Intelligence Agency, see also: www.lenr-canr.org

⁵⁰ DIA-080911003, page 6.

⁵¹ http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20120009038_2012008934.pdf

⁵² Xiaoling Yang and George H. Miley, *A Game-Changing Power Source Based on Low Energy Nuclear Reactions (LENRs)*, presentation at NETS 2012, March 19-23, 2012

4.4 Transmutation of radioactive waste

Transmutation of nuclides present in spent nuclear fuels into stable nuclides has been performed by Yasuhiro Iwamura at Mitsubishi Heavy Industries⁵³. These experiments have been independently replicated by Toyota Central Research and Development Laboratories⁵⁴, with the Osaka and Iwate Universities in Japan also replicating the experiments.⁵⁵ Successful experiments have included transmutation of $^{133}\text{Cs}_{55}$ to $^{141}\text{Pr}_{59}$ and $^{88}\text{Sr}_{38}$ to $^{96}\text{Mo}_{42}$.

Francesco Piantelli has a patent pending for treatment of radioactive waste, WO/2013/046188 – *A Method and a device for treating radioactive material*, published on 4th April 2013. On 16th April 2013, SPAWAR was granted a patent US 8 419 919, *System and method for generating particles*, where “Generated particles may be captured by other nuclei to create new elements, to remediate nuclear waste...”. If this method of transmutation can be scaled up, and operated at a reasonable cost, it may be a way of dealing with the hazardous waste nuclides from present-day spent nuclear fuels, which cannot be used as fuels in Generation IV reactors.

4.5 Consumer products

Defkalion has announced that it is licensing its technology to a number of manufacturers of consumer products. It states that it will itself commercialise its technology for ship propulsion. If this is successful, it will compete with electricity for charging mobile phones and powering various types of mobile consumer products. Defkalion’s managing director, Alex Xanthoulis, has stated that:⁵⁶

- Defkalion is working with six companies to develop special applications. Many of these companies are among the world’s top ten leaders in their field.

⁵³ Y. Iwamura, *Observation of Nuclear Transmutation Reactions induced by D2 Gas Permeation through Pd Complexes*, in Eleventh International Conference on Condensed Matter Nuclear Science, Marseille, France 2004 and <http://indico.cern.ch/getFile.py/access?resId=5&materialId=slides&confId=177379>

⁵⁴ Presentation of Yasuhiro Iwamura at the American Nuclear Society LENR session 2012-11-14 in San Diego, The presentation can be seen on a video: <http://www.lenr-coldfusion.com/2012/12/09/yasuhiro-iwamura-ans-presentation-lenr-transmutation/> and scientifically published: T. Hioki, N. Takahashi, S. Kosaka, T. Nishi, H. Azuma, S. Hibi, Y. Higuchi, A. Murase, T. Motohiro, *Inductively Coupled Plasma Mass Spectrometry Study on the Increase in the Amount of Pr Atoms for Cs-Ion-Implanted Pd/CaO Multilayer Complex with Deuterium Permeation*, Jpn. J. Appl. Phys. 52 (2013) 107301 (8 pages), DOI: 10.7567/JJAP.52.107301

⁵⁵ <http://www.e-catworld.com/2012/12/report-toyota-replicates-mitsubishi-lenr-transmutation-experiment/> 2012-12-07

⁵⁶ <http://matslew.wordpress.com/2013/07/24/comments-on-defkalion-reactor-demo-in-milan/> 2013-08-15

The applications involved are unmanned aerial vehicles, computers, domestic hot water heaters, electricity generation, greenhouses, ship propulsion, vehicles, desalination/purification of water, and large turbines.

- Licence agreements for the manufacture of consumer products have been signed with companies in Italy, France, Greece (Defkalion 50 %), Canada and South Africa. Interest has also been expressed by 1300 companies in about 78 countries. The price of a licence has hitherto been EUR 40.5 million.

5 Questions for the electricity industry

It can be seen that LENR effects can be demonstrated in laboratory experiments. What is missing is proof that the energy conversion process is suitable for industrial production of electricity and heat. Experience from development of other technologies shows that practical problems can arise along the road to commercialization. For this reason, there is therefore considerable uncertainty as to if and when the process might be commercialised.

The Leonardo Corporation's Hot Cat reactor was validated by several university scientists acting on their own. Although their validation has attracted academic criticism, the results seem very plausible.⁵⁷ A Hot-Cat reactor operates at high temperature, which means that much of its energy output is delivered as radiation.

The performance of earlier LENR reactors has been measured by calorimetric means, with flow calorimetry giving the most accurate results. Calorimetry is a particularly suitable method for lower temperatures, with energy being delivered by convection. This is presumably why the more complicated method of measurement involving measurement of radiation has therefore been chosen for validating the Hot Cat reactor. In their article, the scientists state that they made conservative calculations, leaving no doubt that there was a substantial energy yield from the reactor of which they measured the performance.

Many questions remain concerning LENR development. If development is successful, some of these questions will be:

- What variations in performance can be expected between mass-produced units?
- What performance levels can be guaranteed, apart from a positive energy yield?
- How does the process work?
- How safe is the equipment?
- Can we rely on its reliability?
- Is it controllable?

⁵⁷ Göran Ericsson, Stephan Pomp, Comments on the report "Indications of anomalous heat energy production in a reactor device containing hydrogen loaded nickel powder" [arXiv:1305.3913] by G. Levi, E. Foschi, T. Hartman, B. Höistad, R. Pettersson, L. Tegnér, H. Essén, arXiv:1306.6364v1 [physics.gen-ph]

- What skills or knowledge will be needed by those operating or maintaining LENR equipment?
- Will LENR be used mainly for commercial production of electricity and heat for sale, or in equipment that requires energy?
- What are the expected production costs of electricity and heat?
- How quickly can LENR technology be introduced to the energy market?
- What are the opportunities for, and risks to, various parties on the market?

5.1 Market scenarios

Is it possible, at this stage, to speculate in future market scenarios? Perhaps it is, but the conditions are hazy. Does LENR exist in practice? Is it a robust technology? Does the process really not emit or generate any external neutrons, magnetic fields, gamma radiation etc.? Can the systems be operated without getting out of control? If the engineers and developers can solve the above problems, we can make a rough sketch of a possible future market. It is very likely that the first stage would be concentrated on the production of heat for industries, residential areas and, perhaps in the longer term, for individual households. The process could also find a use in the third world for such purposes as low-cost desalination of sea water.

Electricity production, either directly or indirectly, would be of interest in the second stage, either by means of direct conversion or conversion via Stirling engines or thermo-ionic converters. Might magnetohydrodynamic (MHD) electricity production come into the picture? Everything depends on creating high temperatures for a low cost.

Present-day development is aimed at electric powering of vehicles. Current scenarios indicate a substantial proportion of battery-powered vehicles and hybrids by 2030. A breakthrough for LENR technology could change this picture.

5.2 Environmental and safety aspects

At least a dozen companies are developing LENR, spurred by the technology's positive features if it can be made to operate on a commercial scale. If successful, it could present the following benefits:

- No carbon dioxide emissions
- No environmentally hazardous chemical substances
- No spread of radioactivity

- No ionising radiation (at least, not outside the apparatus)
Virtually sustainable (requiring very little process material, and using zirconium which has the benefit of naturally occurring abundantly)
- Low production costs (the raw materials are nickel and hydrogen, available at low cost)
- Small and compact units (easy to install where required)
- Modular technology, suitable for large-scale power generation (easy to scale up and down).

The matrix on the next page compares different energy sources and processes in terms of their carbon dioxide neutrality, renewability and sustainability.

	Carbon dioxide neutrality	Renewability	Sustainability
Fossil fuels	No	No	No
Nuclear power (fission)	Yes	No, but large quantities of uranium in sea water	No
Biomass, wood fuels without returning the ash	Yes, if accompanied by replanting	Yes, but with changes to the mineral content in the ground	No/Yes, depending on ground conditions, and Yes if no social obstacles
Biomass, wood, with ash return	Yes, if accompanied by replanting	Yes	Yes, if no social obstacles
LENR	Yes	No, but no fuel limitations	Yes, if no social obstacles
Solar and wind	Yes	Yes	Yes, if no social obstacles
Hydro power	Yes	Yes	Yes, if no social obstacles

5.2.1 Unknown negative properties

What the negative properties are will remain unknown until industrial users are able to test the reactors by trying them out in the applications for which they are intended. Laboratory-scale tests in university environments are not sufficient to find the downsides of the technology, although such testing is needed before scaling up to industrial testing. All drawbacks that are identified must be investigated, as knowledge of such drawbacks has so far not been publicly investigated. Little information is available on process details, due to patent applications and immaterial rights.

The LENR process seems to require very precise conditions in order to be able to operate, which means that safety considerations must be clarified. Reports indicate that high electric and magnetic fields are created, which can introduce a need for screening.⁵⁸ Whatever the technical status of various LENR reactor designs is, this is an area which will require resolution within energy sectors if LENR companies succeed in launching their products.

The competitiveness of LENR technology with other energy sources depends not only on economic conditions, but also on environmental conditions and on what value is attached to them. The table on the previous page compares various environmental aspects: in addition to them, LENR is claimed to produce no hazardous emissions to air or the ground, and not to produce any environmentally hazardous ash.

5.2.2 Safety aspects

One important aspect of LENR technology is, of course, that of how safe it is. What effects can arise? Does the process create neutrons, and how much gamma radiation may be emitted? Are there problems with explosions, and how is operation maintained stable, with adequate safety margins? All these questions must reasonably be answered at an acceptable level before the technology can be taken up.

⁵⁸ See fig. 5 by Y. Kim and J. Hadjichristos o
<https://mospace.umsystem.edu/xmlui/handle/10355/36783> 2013-08-12

6 Conclusions

What conclusions can be drawn from current research and development of LENR-associated phenomena?

6.1 What is the current status of LENR research?

Today, LENR research is no longer concerned with what is believed or not: instead, it is concerned more with being constructively sceptical and accepting that certain LENR apparatuses seem to deliver more energy than they should reasonably do on the basis of classical assumptions concerning the underlying processes. It will certainly be a while before all aspects of this particular technology have been investigated. Many validations of the LENR technology are being performed today. Various types of apparatus are patented. Some have been built, and several have been tested in more or less independent trials. Studies are being carried out in the defence industries, the space industry etc. Different companies are engaged in tests: some universities are starting to run courses, while others are tackling more fundamental studies that can be linked to LENR. However, it is not yet clear as to which companies will be first to commercialise the technology.

6.2 Where are the explanations?

It is at present difficult to assess the degree of scientific rigour behind the tests, validations and results that are being presented. But perhaps this is of lesser importance? "Results are results", and the theory can come along later. LENR technology might represent a fundamental paradigm shift in the energy sector. The work now being performed should give rise to a pause for thought, coupled with careful but positive skepticism. Based on the material that we have described in this study, we can say that the LENR phenomena that have been presented can be linked to:

- Strongly non-linear processes
- The presence of electromagnetic fields
- Stimulation of systems' various fundamental resonance phenomena in plasma or solid states
- Plasma phenomena in wholly or partly ionised gases, and also in what are known as dusty plasmas
- High energy yields as a result of various possible nuclear reactions, transmutations etc.

6.3 Where are the greatest challenges?

If the LENR process depends on quantum-physics mechanisms, there is probably some non-linear effect involved. It is also very probable that there is some electrodynamic effect with resonances that is playing a part. This means that it may be difficult to control upscaling effects. In the same way, it does not seem entirely straightforward to find a balance between the number of control parameters and control of the system. What is the interaction between thermal and electrical processes?

The Leonardo Corporation's E-Cat reactor requires an external heat input in order to operate. This external heat source also seems to be essential in order to control the equipment safely. Other LENR apparatuses are based on excitation of system resonances: just how these are chosen and controlled are still commercial secrets that cannot be made out from the patent documents. All this means that the challenges facing LENR technology – if it should be found to work – form a complex process, but not necessarily a complicated process. One possible development scenario is that of continuation of a large number of trial-and-error experiments in order to find a means of precise control and repeatability. Safety aspects need to be carefully investigated, particularly concerning the presence of high-energy particles and radiation, magnetic fields etc.

7 References

7.1 Articles, reports and minutes

- Johan VeigaBenesch (Ed), Forward Looking Workshop on Materials for Emerging Energy Technologies, EUR 25350 EN, European Union 2012
- C. Borghi, C. Giori, A.A. Dall'Olio, Experimental Evidence of Emission of Neutrons from Cold Hydrogen Plasma?, American Institute of Physics (Phys. At. Nucl.), vol 56, no 7, 1993.
- F. Celani's presentation at CERN Colloquium, 22 March 2012, <http://indico.cern.ch/getFile.py/access?resId=3&materialId=slides&confId=177379>. Other presentations at <http://indico.cern.ch/conferenceDisplay.py?confId=177379>
- Nicolas Chauvin, LENR Powered Electric Vehicles, Proceedings ILENRS -12, Williamsburg, USA, July 1-3, 2012
- Terry Copeland, Catalyst Hydrino Transition (CIHT) Electrochemical Cell Validation, November and December 2011
- DIA 08-0911003, 2009-11-13, with the title Technology Forecast: Worldwide Research on Low-Energy Nuclear Reactions Increasing and Gaining Acceptance
- DIS Scientific & Technical Memorandum 55/2/00
- Clemmow Dougherty, Electrodynamics of Particles and Plasmas, John Wiley & Son, 1969
- Göran Ericsson, Stephan Pomp, Comments on the report "Indications of anomalous heat energy production in a reactor device containing hydrogen loaded nickel powder" [arXiv:1305.3913] by G.Levi, E.Foschi, T.Hartman, B.Höistad, R.Pettersson, L.Tegnér, H.Essén, arXiv:1306.6364v1 [physics.gen-ph]
- H. Essén, *Catalyzing Fusion with Relativistic Electrons*, arXiv:physics/0607138v1 [physics.plasm-ph], July 2006 ELFORSK 41
- H. Essén, *Classical diamagnetism, magnetic interaction energies and repulsive forces in magnetized plasmas*, Europhysics Letters (EPL) 94, (2011) pp. 47003-1-5
- H. Essén, *The exact Darwin Lagrangian*, Europhysics Letters (EPL) 79, (2007) pp. 60002-1-3

- M.W.Evans, H. Eckardt, D.W. Lindstrom, *New ECE equation from the fundamental definition of the tetrad and application to low energy nuclear reaction*, for publication in Journal of Foundations of Physics and Chemistry 2013 2 (1)
- Fitzgerald M., *Quarterly Journal of the Meteorological Society, First Quarter 1878*, Publisher The Royal Society, London, 1878, pp 160-161.
- Nick Glumac, *Final Consultant Report*, January 2012
- M. Greenwald, *Density limits in toroidal plasmas*, Plasma Phys. Control Fusion 44 (2002) R27-R80
- T. Hioki, N. Takahashi, S. Kosaka, T. Nishi, H. Azuma, S. Hibi, Y. Higuchi, A. Murase, T. Motohiro, *Inductively Coupled Plasma Mass Spectrometry Study on the Increase in the Amount of Pr Atoms for Cs-Ion-Implanted Pd/CaO Multilayer Complex with Deuterium Permeation*, Jpn. J. Appl. Phys. 52 (2013) 107301 (8 pages), DOI: 10.7567/JJAP.52.107301
- Leif Holmlid, *Large ion-cluster HN+ of Rydberg Matter: Stacks of planar clusters H7*, International Journal of Mass Spectrometry, Vol. 300, Issue 1, 30 January 2011, pp 50–58
- Hyperion device Functional & Performance Test Plans & Test Results, test code: 3.2.30,
http://iccf18.research.missouri.edu/files/day2/Protocol_and_test_results.pdf
- H. Ikegami, T. Watanabe, R. Pettersson och K. Fransson, *Ultradense Nuclear Fusion in Metallic Lithium Liquid*, A report on research performed at the R&D Center, Sakaguchi E.H VOC Co. under the auspices of the Swedish Energy Agency, ER 2006:42
- H. Ikegami, *The Nature of the Chemonuclear Transition*, TSL note, Uppsala 2012
- Independent Technology Evaluation Study, Phase 1 – Test Plan Development for BlackLight Power CIHT Technology*, January 2012
- Y. Iwamura, *Observation of Nuclear Transmutation Reactions induced by D2 Gas Permeation through Pd Complexes*, in Eleventh International Conference on Condensed Matter Nuclear Science, Marseille, France 2004
- Yeong E. Kim, John Hadjichristos, *Theoretical Analysis and Reaction Mechanisms for Experimental Results of Hydrogen-Nickel Systems*, Purdue Nuclear and Many Body Theory Group (PNMBTG) Preprint-PNMBTG-10-2013 (October 2013). Invited paper presented at ICCF-18, University of Missouri, July 21-27, 2013

- Lerner E., *Magnetic self-compression in laboratory plasmas, quasars and radio galaxies; Part I*, Laser and Particle Beams (1986) vol 4, part 2; pp 193-213
- Giuseppe Levi, Bologna University, Evelyn Foschi, Bologna, Torbjörn Hartman, Bo Höistad, Roland Pettersson and Lars Tegnér, Uppsala University, and Hanno Essén, Royal Institute of Technology, Stockholm, *Indication of anomalous heat energy production in a reactor device*, 2013-05-16, with latest revision 2013-06-07, <http://arxiv.org/abs/1305.3913v3> [physics.gen-ph]
- Lewis E., Consideration about Plasmoid Phenomena and Superconductivity Phenomena, <http://padrak.com/ine/ELEWIS5.html>
- Matsumoto T., Experiments of One-Point Cold Fusion, Fusion technology, 24, 332 (Nov 1993)
- Michael A. Nelson, John Hadjichristos et al., *Test Plans & Test Results, Hyperion lab devise Functional & Performance Test Protocol*, September 2012
- Friedrich Panethand, Kurt Peters, *Über die Verwandlung von Wasserstoff in Helium*, Naturwissenschaften 14 (43): pp 956–962.
- Fabio Penon, *Report on the internal test performed on the "hot cat"*, 2012-07-16
- Fabio Penon, Test report published by Leonardo Corporation 2012-10-09
- James K. Pugh, Ethirajulu Dayalan, *Evaluation of Electrical Power Generation by BlackLight Power's Catalyst Induced Hydrino Transition (CIHT) Cells*, April 2012
- K.V. Ramanujachary, *Validation of Electrical Power Generation by Second-Generation CIHT Technology*, November 2011 SGS Italia S.p.A., Voluntary Certificate of Compliance with Safety Requirements of Directive 2006/42/EC (Annex I)
- Sanduloviciu et al., *Non-linear phenomena in plasma as a consequence of self-organization*, Dept. Of Plasma Physics, Al.I.Cuza Univ., 6600 Lasi, Romania
- Seward. C et al., *Ball Lightning explained as a stable plasma toroid*, <http://www.electronpowersystems.com/>
- P. K. Shukla and B. Eliasson, *Novel attractive force between ions in quantum plasmas*, Phys. Rev. Lett. 108, 165007 (2012); Erratum: PRL 108, 219902(E) (2012); PRL 109, 019901 (E) (2012), DOI: 10.1103/PhysRevLett.108.165007
- S. Son, N.J. Fisch, *Pycnonuclear reaction and possible chain reactions in an ultra-dense DT plasma*, Physics Letters A 337 (2005), pp 397–407

- Y. N. Srivastava, A Widom, L Larsen, *A primer for electroweak induced low-energy nuclear reactions*, PRAMANA – Journal of Physics, vol. 75, No. 4, October 2010, pp 617-637, DOI: 10.1007/s12043-010-0143-3
- Edmund Storms, *Status of cold fusion*, Naturwissenschaften, October 2010, Volume 97, Issue 10, pp 861-881
- J. Swain, A. Widom, Y. N. Srivastava, *Electrostrong Nuclear Disintegration in Condensed Matter*, [http:// arXiv:1306.5165v1](http://arXiv:1306.5165v1) [nucl-th] 19 June 2013
- Henry Weinberg, *CIHT Validation Report*, January 2012
- A Widom, L Larsen, *Ultra low momentum neutrons catalyzed nuclear reactions on metallic hydride surfaces*, European Physical Journal C – Particles and Fields, vol. 46, No 1, April 2006, 107-112, DOI: 10.1140/epjc/s2006-02479-8
- Widom, J. Swain, Y.N. Srivastava, *Weak Interaction Neutron Production Rates in Fully Ionized Plasmas*, <http://arXiv:1305.4899v1> [hep-ph] 19 May 2013
- X. Yang, G. H. Miley, *A Game-Changing Power Source Based on Low Energy Nuclear Reactions (LENRs)*, presentation at NETS 2012, March 19-23, 2012
- M. Zuin et al., *A first principles explanation for the density limit in magnetized plasmas*, arXiv:1001.4480 [physics.plasma-ph] (2010)

7.2 Web sites

- http://aromapress.com/~defkalio/wp-content/uploads/2013/01/2011-11-30_Hyperion-Spec-Sheet.pdf
- <http://www.blacklightpower.com>
- <http://brillouinenergy.com/>
- <http://cdn.coldfusionnow.org/wp-content/uploads/2012/12/HagelsteinPdemonstra.pdf>
- <http://coldfusiondevices.com/cold-fusion/cold-fusion-devices-to-power-cars-in-the-future>
- <http://drmyronevans.files.wordpress.com/2013/10/paper230.pdf>
- <http://ecat.com/ecat-products/ecat-1-mw>
- <http://ecat.com/ecat-products/ecat-ht-hot-cat-prototype>
- <http://www.e-catworld.com/2012/12/report-toyota-replicates-mitsubishi-lenr-transmutation-experiment/>, 2012-12-07
- <http://www.e-catworld.com/2013/04/celani-warns-of-lenr-explosions-at-low-temperatures/>

<http://www.enea.it/it/Ufficio-Bruxelles/news/new-advancements-on-the-fleischmann-pons-effect-paving-the-way-for-a-potential-new-clean-renewable-energy-source>

<http://energycatalyzer3.com/news/toyota-is-active-in-cold-fusion-research-again>

<http://episin.blogspot.se/2011/07/brillouin-energy-reactor-being-tested.html>

<http://www.forbes.com/sites/markgibbs/2013/05/20/finally-independent-testing-of-rossis-e-cat-cold-fusion-device-maybe-the-world-will-change-after-all/>

<http://indico.cern.ch/getFile.py/access?resId=5&materialId=slides&confId=177379>

http://iccf18.research.missouri.edu/files/day2/SKINR_Overview.pdf

<http://jet.xvm.mit.edu/>

<http://www.kresenn.com/> <http://lenr-canr.org>

<http://www.lenr-coldfusion.com/2012/12/09/yasuhiro-iwamura-ans-presentation-lenr-transmutation/>

<http://matslew.wordpress.com/2013/07/24/comments-on-defkalion-reactor-demo-in-milan/>

<https://mospace.umsystem.edu/xmlui/handle/10355/36783>

<http://newenergytimes.com/v2/sr/WL/WLTheory.shtml>

<http://new.livestream.com/triwu2/Defkalion-US>

<http://nextbigfuture.com/2012/04/brillouin-had-los-alamos-and-sri.html>

<http://nextbigfuture.com/2012/06/mit-lenr-device-publicly-running-for-6.html>

http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20120009038_2012008934.pdf

http://old.enea.it/com/ingl/New_ingl/publications/pdf/Cold_Fusion_Italy.pdf

<http://pappengine.com/videos.htm>

http://peswiki.com/energy/PowerPedia:Joseph_Papp%27s_Noble_Gas_Engine

<http://www.plasma-universe.com>

http://roma.repubblica.it/cronaca/2012/04/19/foto/il_reattore_costruito_dagli_studenti-33583028/1/

<http://www.slideshare.net/ssusereef70/brillouin-bus-sum4512>

<http://www.slideshare.net/ssusereef70/brillouin-ppt-technical32712>

<http://student.mit.edu/searchiap/iap->

[BD6D0CF8E170B284E0400312852F4A61.html](http://student.mit.edu/searchiap/iap-BD6D0CF8E170B284E0400312852F4A61.html)

<http://world.std.com/~mica/cft.html>

<http://22passi.blogspot.se/2012/04/lathanor-delliis-pirelli-di-roma-1.html>

8 Appendices

8.1 Patents

LENR-associated patents have been taken out over the last couple of decades. The following is a selection bearing on processes approaching the commercialisation stage. When working installations are available for public inspection on the market, it can be assumed that the patent applications that have been submitted will be granted.

8.1.1 USA

On 12th April 1989, MIT submitted its application for a patent based on theoretical work by Peter L. Hagelstein, under the name of *Fusion apparatus* WO1990013129 A3, published on 29th November 1990. Peter Hagelstein has also applied for a patent under the title *Methods and apparatus for energy conversion using materials comprising molecular deuterium and molecular hydrogen-deuterium*, WO2006128109 A3, publication date 11th October 2007, WO2006055294 A3, publication date 13th December 2007, Method of and apparatus for thermal energy-to-electrical energy conversion WO2008017924 A3, 18th December 2008.

On 2nd December 1993, the University of Utah licensed all its LENR patents to ENECO, a new company that had been set up to exploit LENR discoveries, but in March 1998 announced that it would no longer defend its patents.

Leonardo Corporation has submitted a patent application in the USA, *Method and apparatus for carrying out nickel and hydrogen exothermal reaction*, with publication number US 2011/0005506 A1, dated 13th January 2011.

Francesco Piantelli's American patent application has the name Thin nano structured layers with high catalytic activity on nickel or nickel alloy surfaces and process for their preparation, 20120134915, dated 31st May 2012.

Brillouin Energy has lodged the following patent applications: *Drive circuit and method for semiconductor devices*, US20070268045 A1, 22nd November 2007, and WO2007137268 A3, 10th April 2008, *Energy generation apparatus and method*, WO2007130156 A1, A2 and A3, 6th September 2007, 15th November 2007 and 31st January 2008 respectively, EP1971985 A2, 24th September 2008, US20110122984 A1, 26th May 2011.

BlackLight Power's electrolytic process is the subject of patent applications dated 18th March 2010, 17th March 2011 and 30th March 2012. The company's dry process has lodged patent applications dated 28th April 2008, 29th July 2009, 18th March 2010, 17th March 2011 and 30th March 2012.

However, the American Patent Office has rejected all patents in the LENR field. Nevertheless, despite this, LENUCO's George H. Miley has succeeded in obtaining a patent, US 8 227 020 B1, under the name of '*Dislocation site formation techniques*', issued on 24th July 2012.

8.1.2 Asia

The American company, Brillouin Energy, has patented its LENR reactor in China: Patents Registry, Intellectual Property Department, The Government of the Hong Kong Special Administrative Region, Application No. 09108065.4, Publication no. HK1132580.

See http://ipsearch.ipd.gov.hk/patent/ereg/fssr02100.jsp?AH_NO=09108065.

8.1.3 Europé

Together with Sergio Focardi and Roberto Habel, Francesco Piantelli sought a patent for *Energy generation and generator by means of an harmonic stimulated fusion*, with publication number PCT/IT95/00008, dated 3rd August. His next patent application, *Method for producing energy and apparatus therefore*, publication number WO2010/058288, dated 27th May 2010, was granted on 16th January 2013 as EP 2 368 252 B1. His third patent application was entitled *Method and apparatus for generating energy by nuclear reactions of hydrogen adsorbed by orbital capture on a nanocrystalline structure of a metal*, WO/2013/0082/19, of 17th January 2013, complemented on 7th March 2013. The *Method for producing energy and apparatus therefore* patent is the only one for nickel/hydrogen LENR that is valid throughout Europe.

Francesco Celani has a European patent application for nanostructured nickel: Nanostructured thin layers having high catalytic activity on surfaces of nickel and its alloys and a process for obtaining them, WO2011/016014A2, 7th February 2012.

Andrea Rossi, of the Leonardo Corporation, has had his application for a European patent for his E-Cat rejected, but has an American application for it under no. US2011/005506 A1, publication date 13th January 2011. However, he does have an Italian patent, *Processo ed apparecchiatura per ottenere reazioni esotermiche, in particolare da nickel ed idrogeno*, no. MI2008A000629, granted on 6th April 2011 and valid until 9th April 2028.

Etiam OY has a patent application for *Thermal-energy producing system and method*, WO2013076378 A2, published on 30th May 2013.

LENR Cars Sàrl has a patent application for *Low Energy Nuclear Thermoelectric System*, US 2013/0263597 A1, published on 10th October 2013.

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