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Challenges, Attractions and Possible Impacts of Commercial Generators Based on Low Energy Nuclear Reactions

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Abstract *Commercialization of LENR sources of power and energy has several challenges. But, if they are overcome, attractive potential advantages and important impacts should follow. These challenges, attractions and possible impacts are cited and discussed. The next few years might reveal which of these factors are realistic.*

Keywords: Low energy nuclear reactions, LENR, commercialization

1. INTRODUCTION

Engineering connects science and business. It requires overcoming challenges to achieve desired goals. This is as true for possible LENR generators of power and energy as it is for both proven and new products of other types. In this paper, we address the challenges to development and production of commercially successful LENR generators. The many and attractive possible products, which drive attempts to overcome the challenges, are also listed and examined. Possible larger-scale impacts of overcoming the hurdles and realizing the advantages of LENR generators are noted.

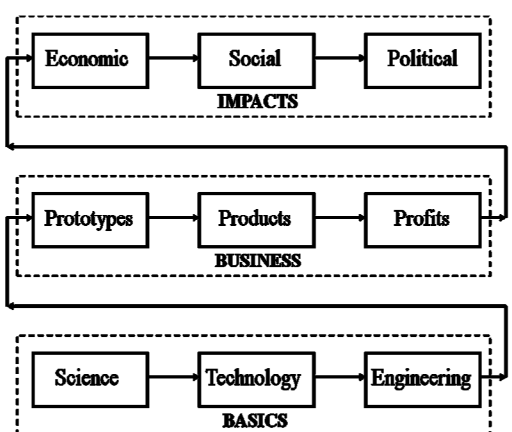

Figure 1. Sequence of phases for moving a promising topic from the scientific laboratory to its achieving commercial success and major impacts.

The next section addresses the challenges in getting from the basic to the business levels, as shown in Figure 1. The third section deals with what fuels the optimism that LENR generators will be very successful commercially. Then, the fourth section considers the possible higher level impacts noted in Figure 1. Some conclusions are noted at the end.

2. CHALLENGES TO COMMERCIALIZATION

The impediments to successful commercialization of LENR power and energy generators fall into two broad categories. The first applies to all products, and the second is more specific to LENR. We note the general challenges, and then focus on those more unique to LENR.

In general, the development and selling of products involves an often-daunting sequence of steps, where failure in any one of them can be lethal to the effort. The development of concepts for, first, prototypes, and then, products is key to success in later steps. Setting of requirements, which document what a prototype or product must do, and specifications, which are numerical embodiments of the requirements, are also critical. Not aiming for high performance increases the likelihood of getting a product to market, but reduces its chance of success. Designing objects involves choices of materials and geometries, usually done with sophisticated software. Design-for-manufacturability is important. Once designed, a potential system can be simulated, again with modern software. Iterating the design and simulations steps is better and cheaper than actually making and testing variations of a design. After a design is frozen, the procurement of parts by purchasing or manufacturing them is the next step. Assembly on all levels from components through modules to entire systems requires skilled technicians, especially early in the life cycle of a product. Integration of components and modules, and even systems, from other manufacturers is commonly required. Testing of performance for comparison with the specifications is unavoidably important. Reliability testing is needed to insure that the product will last long enough in the hands of customers. Some type of safety testing is also mandatory for most products. Regulatory approval is needed for many products. Distribution, sales and customer service are all critical to the success of a product. Maintenance and end-of-life considerations are also significant. All of these factors apply to possible LENR generators. But, they also have some more specific challenges, as described now.

A. Reproducibility and Controllability

It is well known that the reproducibility and control of LENR experiments have been, and continue to be major problems. Promises by Leonardo Corp and Defkalion Green Technologies to have products on the market in 2013 imply that they have overcome both reproducibility and controllability challenges. However, they have provided no information to make that case.

Reproducibility is a fundamental requirement. It is widely thought that there are materials issues with LENR systems that are still not understood, which determine whether excess heat is produced and at what levels. If that is indeed the case, it will be necessary to tightly control the materials that are at the core of LENR generators. Also inescapable is the requirement that the materials remain effective during the lifetime of the generator or between refueling events. The need for precision materials might turn out to drive up the cost of power and energy from LENR. Maintenance of materials effectiveness, especially at high temperatures for adequately-long times might also be costly. That is, the overall generator must be made to operate in such a fashion that it produces power at sufficient levels, but does not self destruct in the process. LENR are generally thought to occur on surfaces. Hence, the management of impurities within a system at the outset, and control of their migration during operation, are critically important. It is known that some materials poison the production of energy by LENR.

Concerning controllability, the automobile is again a good paradigm. LENR generators, like cars, must be able to be turned on, up, down and off at will. If needed, they must also produce output at desired and steady levels, much as a thermostat in a room will keep the temperature nearly constant. Figure 2 shows the most basic control loop as it applies to LENR generators. Either people or a programmed computer will input the set point for the system. That will cause the operation of some actuator to determine the output of the generator. Sensors will feed back the achieved level of performance for comparison with the set point, and possible further actuation. The concept is simple, but there are many questions. What are the control parameters? Will hydrogen pressure, in the case of a LENR generator using hydrogen, provide sufficient control? Or, must the temperature in the reactor also be controlled? In the case of units that work on the basis of interior plasmas, will the level of plasma ionization provide a useful control parameter? What actuators will be effective? There are multiple ways to control pressure, temperature and plasma characteristics. Which will work, be durable and prove cost-effective? What sensors are needed? Will simple point sensors for determination of pressure or temperature suffice? Or, will more sophisticated sensors or sensor subsystems be needed? What are the response times of the actuators, sensors and the LENR generator itself? Different applications will

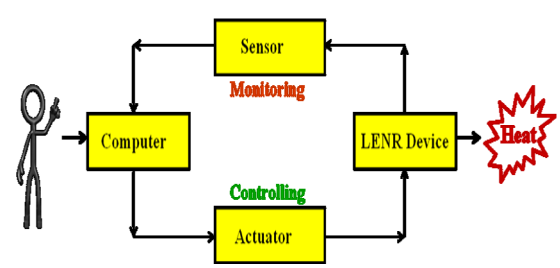

Figure 2. Control loop for a LENR thermal energy generator showing a person setting the output.

require various response times. And, how stable will be the output power? Consider the desirability of consistent hot water in a shower.

B. Reliability and Durability

Reliability deals with the consistency of the output of a LENR generator for the same control parameters. What would it be like if an automobile did not respond the same way each time the engine is started? Experimental demonstration of the reliability of production of heat by LENR is still in its infancy and far from what is needed commercially. No study of permissible variations in the output of a LENR generator is known to this author. It is obvious that what variations can be tolerated depends on two factors. The first is acceptable variations in the temperature of the output, which will be very application dependent. The second is the thermal mass of the material or machine into which the LENR heat is transferred. A large industrial vat might be much less sensitive to temperature fluctuations than a small amount of material or small system. If a LENR generator is used to drive an electrical source, quite steady thermal output might be needed. Will it be necessary to have an electrical generator that relies on LENR to be integrated with the grid as a backup for uninterrupted power? Or, might LENR electrical generators be used themselves as backup sources of electricity?

Durability for LENR generators is another critical aspect of their performance which is unknown. LENR generation of energy in experimental setups, at levels which are commercially interesting (say, greater than 100 W), has been demonstrated for weeks and a few months, but not the longer times needed for successful commercial products. The heating and air conditioning (HVAC) units now in homes are instructive. They often require maintenance annually, but the system must last for at least a decade. It is a given that production and operation of current HVAC units are based on decades of engineering and commercial experience. Decades from now, LENR generators might enjoy a similar base of empiricism in their manufacture, maintenance and use. But, it is difficult now to be certain that such will turn out to be the case, and when. Even if LENR generators are relatively cheap and perform well, replacing them is a hassle similar to switching out the heating and cooling unit in a home.

C. Safety and Regulations

There is a significant probability that LENR generators will prove to be safe. In fact, this is one of their potential advantages, as discussed below in Section 3D. However, there are two reasons to be concerned about the safety of such generators at this point in their development and commercialization.

The first concern is due to the occurrence of sudden releases of significant energy in past LENR experiments. The most notable is singular event described in a paper by Fleischmann and Pons in 1989 [1]. They were conducting an electrolytic LENR experiment in which the cathode was a cube of Pd 1 cm on a side. During the night, the experiment suffered a thermal runaway, which lead to the following statement in their paper: "WARNING! IGNTION! We have to report here that under the conditions of the last experiment, even using D_2O alone, a substantial portion of the cathode fused (melting point 1554 ^oC), part of it vaporized, and the cell and contents and a part of the fume cupboard housing the experiment were destroyed." There have been a few other relatively large releases of energy in LENR experiments that could not be ascribed to chemical causes.

The second reason for caution regarding the safety of LENR generators is the lack of full reproducibility and controllability. These shortfalls make it difficult to produce several generators that are essentially identical in design, construction and performance. Having such a set of generators would make it possible to drive them at different output power levels to experimentally determine when they become unsafe. Similarly, it is desirable to have another set of reactors that are similar in design, but vary in size and the amount of active materials they contain. The second set would also enable key tests of safety. Of course, the generators that will become available from different vendors will have various designs. Hence, what is learned from safety testing of a set of reactors of one design might not carry over to another company's products. Testing the safety of

LENR generators will continue for many years after they are on the market in large numbers.

It is common for governments to regulate commonly used services and devices, especially those that pose safety concerns. Federal, state and even local governments in the US have strong opinions on devices based on nuclear reactions and on consumer safety generally. Takoma Park, Maryland, a city of less than 20,000 residents near Washington DC, has declared itself a "nuclear free zone". That means they ban nuclear power as well as nuclear weapons (but not nuclear medicinal or nuclear research equipments). The point is that even a small locality could decide to ban power generators based on LENR. Some states in the US have product safety organizations. For example, California has a Consumer Services Center and New York State has a Division of Consumer Protections. The US government set up the Consumer Product Safety Commission in 1972 to protect the populace against "unreasonable risks of injuries associated with consumer products". It now has jurisdiction over nine categories of products. It is possible that the Commission could also be made responsible for the safety of LENR generators.

It will be interesting to see if jurisdictions on various levels move to regulate the sale and use of LENR generators. Such moves will be influenced by two factors. One is early accidents involving LENR generators, maybe even if they are due to problems with steam or electricity. The other is negative public perceptions of energy systems based on LENR.

D. Public Perceptions

Even if LENR generators can be shown to have high performance at low costs, and to be reasonably safe, there is another hurdle to their widespread adoption in some countries and regions. The public remains generally ignorant and fearful of things nuclear. This is despite the fact that we are all made of atoms containing nuclei, and we are all radioactive (due to ^{40}K). The medical imaging technology based on the mechanism Nuclear Magnetic Resonance (NMR) was brought to market as Magnetic Resonance Imaging (MRI). That is, the word "nuclear" was not used in its title. The performance, reliability and acceptance of LENR generators all remain to be determined. It is possible, like genetically-modified foods in Europe, they will get a bad reputation, and be either shunned or banned in some regions. But, it is also possible that the cost-effectiveness of LENR generators will lead to the public adopting them, even to the point of setting aside their fears of nuclear energy.

3. ATTRACTIONS OF LENR GENERATORS

The goals that are now driving many people and organizations to confront the challenges cited above are determined by the possible advantages of LENR power and energy sources. These advantages were discussed in some detail in a recent article, which is available on the web [2]. That article did not organize the various expected advantages of LENR power and energy generators into categories. Such is done in the rest of this section. Rather than repeat the long discussion of each advantage here, we provide lists in each category, with only a few comments on each potential advantage. It will be clear that some of the attractive advantages of LENR generators apply to more than one of the listed categories.

It must be noted that most of the items listed below have not been adequately validated. The list suffers from including too many still unproven assertions by Andrea Rossi of Leonardo Corporation and by Defkalion Green Technologies S. A., among other organizations and individuals. Both the lack of any validated theory to explain LENR, and what seem to be overly-optimistic views of LENR applications, offends many commentators. Lack of scientific understanding is one thing. A set of potential properties that seems too good to be true is something else. The compilation in this section deals with, and possibly contributes to the second of these perceived problems with LENR.

A. High Performance

It is widely expected, but not yet proven that LENR generators will have high and versatile performance. These expectations are based on the following possibilities:

High Energy Gains. Energy gains are defined as the ratio of energy out of a system to the energy required to operate it. Very high gain values have already been reported, but not yet adequately verified. They involve thermal output energy stimulated by electrical input energy. Energy gains in excess of 25 using the electrochemical D-Pd system have been published. Energy gains exceeding 400 have been reported on the web for the H-Ni gaseous system.

Sustained ("Burning") Reactions. One goal of hot fusion research is achievement of burning, where the energy released by prior reactions sustains continued energy release, as long as fuel is available. That situation is entirely analogous to the lighting of a pile of logs with a match. It may also be applicable to LENR. Such sustained operation can lead to enormous energy gains, since the output thermal energy continues to increase without increase in the input electrical energy.

Production of Heat. The raw output thermal energy from LENR generators can be used to raise the temperature of diverse working fluids. Such liquids can be water or organic substances. The production of thermal energy for homes, offices and factories will be a primary function of the earliest commercial LENR generators.

Generation of Electricity. Electrical power is needed almost everywhere, so the use of energy from LENR devices to generate electricity is also of great interest. If steam is produced, it can be used to run a turbine or other engine attached to an ordinary alternating-current electrical generator. There is also great interest in development of thermoelectric materials now, independent of LENR. The motivation is the ability to use energy wasted in many devices and processes to produce direct current. Available inverter technologies can be used to produce AC from the DC coming from LENR devices, which are integrated with thermal-to-electrical transducers.

B. Low Costs

Rossi projects that costs for the purchase, operation and maintenance of LENR generators will be relatively inexpensive. Specific features include the following:

Cost Leverage. Here again, it is hard to be confident about the prospects for LENR sources of power and electricity. But, predictions have already been made. Rossi has asserted two particularly interesting numbers. The first was his expectation that electricity produced with his E-Cat units would cost only about 2 cents per kW-Hr. That is less than 20% of the cost of power in most of the US now. The numbers for production of thermal energy using E-Cats are even more compelling. Rossi estimated that the amount of nickel in a US five cent coin, that is, 1.25 grams, would produce energy equivalent to five barrels of oil. What if the nickel in the coin produced energy equal to "only" one barrel of oil? A barrel of oil costs roughly $100. Hence, the fuel cost of a LENR thermal source could be 20 x 100 = 2000 times less than oil.

Low Capital Cost. Since LENR generators are not already on the market, it is difficult to project costs of units, even those now promised for sale during 2013. Defkalion have not yet commented on costs for their projected multi-kilowatt units. However, Rossi has stated that he expects the cost for his few kW units to be about $50 per kilowatt.

Low Cost for Refueling. The cost for using LENR generators includes the outlays needed for fuel and for maintenance, in addition to amortization of the capital costs. Rossi expects that the E-Cat units will have to be refueled every six months at a cost of $10 per event. There has been little discussion of maintenance costs by Rossi or anyone.

Long Operational Lifetime. The LENR generators now being planned for sale are relatively simple devices. They do require pumps for the working fluid, but it is conceivable that such pumps can be replaced as are fan motors in home HVAC units. If something as complex as an automobile can last for more than a decade, assuming proper care, it is plausible that LENR generators will remain useful for two or three decades. Rossi has asserted that lifetimes of his units might be 30 years. If a home LENR unit costs, say, $300 and lasts for 30 years, the average annual capital cost would be much less than the price of one ticket to a movie theater.

Potential for Rapid Adoption. One of the advantages of LENR power generators is that they might be widely adopted very quickly. There are two reasons why the adoption of LENR generators on a very large scale might happen relatively fast. The first is that they are not complex systems. The second reason for fast adoption of LENR energy generators is economic. If they are as cheap to buy, operate and refuel as projected, they will lead to remarkable savings on energy for consumers. As sales volumes increase, unit prices are likely to decline.

C. Operational Advantages

Silent Operation. One of the standout characteristics of LENR power sources is the absence of acoustic emissions during their operation. Unlike automotive and other engines, there are no explosions within LENR devices. They might operate in a continuous mode during the production of power, with either constant or quietly pulsed input electrical power, or no electrical input power, once started. To appreciate the value of silent operation, consider the noise made by conventional electricity generators that have gasoline engines.

Easy Operation and Refueling. The units now planned for the market apparently will require little training in their use and little attention during their operation. It remains to be seen if commercial LENR units can be controlled much as thermostats are now set by homeowners. The on-going development of means to store energy for solar and unsteady sources of energy might prove useful for storage of LENR energy. Rossi asserts that the E-Cat devices can be refueled simply by capable homeowners. That is, it may not be necessary to call in trained service personnel for refueling.

Long Times Between Refueling. The currently projected times of six months between refueling of E-Cat systems might not seem very long. But, they are long compared to the times for refueling generators that burn hydrocarbons.

Opportunities for Optimization. Both the LENR experiments already conducted and the prototypes that have been demonstrated are virtually certain not to be as good as those designed and developed later. Commercial products are generally improved over time to give better performance for the same or lower costs. The point is that the production and use of LENR thermal and electrical generators are now in the earliest stages of commercialization. Optimization of manufacturing processes, which will lower costs of LENR generators, can also be expected.

D. Safety Possibilities

Safe Operation. The safety of power sources and energy transduction devices is an enduring concern. LENR generators, no matter how attractive their performance, must be safe. Focardi and Rossi reported energy gains of 415 in a web-posted paper in March of 2010. Why are Leonardo and Defkalion now envisioning commercial devices with gains of "only" 5 to 30? It is probably because of safety concerns. That is, LENR generators with very high energy gains might not be adequately controllable for commercialization.

Fail Safety. The control of the output of any power source is a necessary concern. It appears that LENR power sources will not offer near-instantaneous responses to changes in input settings. That is no problem for a wide variety of expected applications, including heating and electricity generation. But, there remains the possibility that the control system for a LENR generator will fail and the system will run away, causing damage to property or injury to people. Rossi has stated that, if the temperatures get too high in one of his devices, they will ruin the ability of the key internal materials to produce energy and automatically shut-down energy production. Fail-safe operation, while expected, still demands clear demonstrations by use of LENR sources that are to be sold.

Easily Shielded Radiation. Many chemical energy sources suffer from concerns over fires and even explosions. However, they are free of anxiety over dangerous radiation emissions, and require no radiation shielding. LENR energy sources are close to chemical energy sources in radiation safety, but they do have small fluxes of energetic radiations that must be and can be shielded easily. One of the hallmarks of the past two decades of research on LENR is the quantification of excess heat without the measurement of dangerous levels of either neutrons or gamma rays, despite vigorous attempts to make such radiation measurements.

Adequately Safe Input Chemicals. Even if radioactive fuels are not needed for LENR reactors, it is possible that what they require for operation could be dangerous for chemical reasons. Of particular concern is the use of pressures of hydrogen gas that might be as high as 200 atmospheres. Very importantly, it is possible that LENR generators will later get their hydrogen from solids rather than high pressure tanks. Some solids, such as lithium aluminum hydride, have four hydrogen atoms per two metal atoms in their molecules. In short, the hydrogen in LENR energy generators might prove to be much safer than gasoline now used in vehicles in large numbers (hundreds of millions).

No Input Radioactivity. The input fuels for current experimental and possible near-term commercial LENR power and energy generators are apparently benign. They are available on the market now, although mixing and other pre-processing for their activation might be needed.

No Radioactive Waste. One of the largest problems with fission reactors is the radioactive waste left in spent fuel rods. Some of the isotopes in such rods have long half lives, so that the waste would remain dangerous for periods on the order of 10,000 years. One of the touted advantages of hot fusion reactors is that their radioactive waste would be dangerous for "only" about 1000 years. Remarkably, the generation of energy using LENR results in essentially no radioactive waste. Sensitive measurements of some materials from LENR experiments have shown evidence of weak emissions of unknown species with unmeasured energies. The weak activity of materials from some LENR experiments might be due to tritium, which decays with a half life of 12.3 years. In short, radioactive waste does not seem to be a problem for LENR energy sources.

E. Environmentally Friendly

No Greenhouse Gas Emission. LENR electrochemical experiments and gas loaded generators have not been shown to produce greenhouse gases during or after the operation of experiments to date. That is, they are free of both radioactive waste and greenhouse gas emissions. This combination of features is remarkable.

No Chemically Dangerous Waste. It is conceivable that operation of a LENR energy generator could be free of significant radiation and residual radioactivity, but still produce chemicals that might harm people. This does not appear to be a concern, based on experience with LENR experiments that produced excess energy.

Possibly Beneficial Waste. If the product of reacting nickel with hydrogen is indeed copper, it should be possible to recover the copper and use it in electrical and other products. Retrieving the copper from LENR generators might be cheaper than mining and refining copper ore. However, the overall economics of materials for LENR generators are unknown, and have not even been properly estimated.

Easy Disposal of LENR Generators. No matter how long they last, LENR sources of power and energy will eventually wear out. So, the question of their eventual disposal needs attention. If, as expected, they do not contain radioactive waste or dangerous chemicals, it might be possible to dispose of them into everyday streams for recycling of metals.

Abundant Hydrogen Fuel. Hydrogen is one of the most common elements on earth. Freeing it from water could be done electrolytically by using a small fraction of the energy produced by LENR generators. The total cost of gaseous hydrogen will not be a significant part of the overall cost of fueling LENR reactors. If protons are gotten from solid chemicals, their cost will still be very small compared to the value of the power they produce during LENR. From an environmental viewpoint, operation of LENR generators should not perturb the distribution of hydrogen on earth significantly.

Abundant Nickel Fuel. Nickel is the 24th most abundant element on earth. About 1.3 million tons of nickel are mined annually. One percent of that amount would be equivalent to the energy from roughly 24 billion barrels of oil. The annual global production of oil is near 30 billion barrels. Hence, a small fraction of the production of nickel could, if reacted in LENR generators, nearly equal the energy equivalent of oil, both on an annual basis. Again, the environmental impacts of using nickel as a fuel in LENR generators might not be disruptive.

F. High Power Density

Small Size. The density of power and energy in sources of heat or electricity are important parameters. The power and energy densities of LENR sources are attractive. This means that, for a given desired output power, the core of LENR generators can be small. Rossi has exhibited hardware with core volumes much smaller than one liter, which reportedly can put out several kilowatts of power. He expects such levels of power from a device about the size of a D cell battery.

Lightweight Systems. Small systems are generally light in weight. The few kilowatt systems now being promised by Leonardo and Defkalion might have weights on the order of a few to a several tens of kilograms. Such systems are within the lifting capability of many adults.

Distributed LENR Generators. One of the greatest projected impacts of small, several kilowatt, LENR generators of heat or electricity is the possibility that they will be in individual homes and other small buildings. Home owners now have considerable control over their *consumption* of electrical energy. If they have their own LENR power generators, they will also have much control over their own *generation* of energy. If, as expected, both heat and electricity are produced locally, then homeowners and other users of electricity would no longer be susceptible to brown- and black-outs due to power station or grid problems. They might be able to produce energy using an as-needed routine.

Fewer Large Power Stations. If distributed LENR generators come to pass, the need for large central power plants will decline. The costs for design, construction, operation and eventual removal of many immense facilities can be avoided. This might be especially important for big fission power plants, which are also burdened by very long approval requirements, great up-front investments and enduring fears among the population about their safety.

Relief for the Power Grid. If there are sources of power near the point of use, especially in homes and offices, but also in factories, there would be less dependence on the grid to deliver electrical energy. The grid is a remarkable technological system, but it costs money to emplace and maintain. And, even if the grid were free, there are inevitable transmission losses between power stations and consumers of electricity. Now, most of the large power stations are coal-fired, so they produce prodigious amounts of greenhouse gases and atmospheric pollutants. The large energy losses, and the concomitant environmental impacts, could be avoided with green LENR power sources located near the users of the power.

Portable Energy Systems. Small size and light weight enable portable and mobile use of the smaller LENR power generators. The ability to move a LENR power source from one location to another would be useful for some applications, like pumping.

Power for Transportation. It seems likely that direct use of LENR power for automobiles, trucks and other vehicles is well in the future. However, it might be possible to employ LENR electricity generators to power batteries for hybrid cars in the nearer future. The timing of this possible application depends on the performance, size, weight, cost and reliability of LENR generators.

Scalability. With LENR, scalability can be achieved by the use of multiple lower-power units. This is the approach taken by Rossi, for example, with his nominal 1 MW unit in the 20 foot shipping container. It reportedly contained 52 modules, each with three E-Cat units. Currently, elementary LENR generators with powers of a few kilowatts are promised by Leonardo and Defkalion. Hence, achievement of systems with tens or hundreds of kilowatts thermal output are feasible. If it is practical to integrate 100 sub-units into an overall LENR generator, the ability to generate any power level from watts to multi-megawatts depends on the availability of the elementary units. Sub-units with powers from one watt to about ten kilowatts would enable production by LENR systems with powers over six orders of magnitude. Sub-units with powers below one kilowatt are not now in sight commercially.

4. POSSIBLE IMPACTS OF LENR ENERGY

If the challenges to commercialization of LENR generators noted in Section 2 are mostly overcome, and if at least some of their potential advantages listed in Section 3 are realized, there are likely to be significant economic, social and even political impacts. Some of the potential impacts of the widespread availability of LENR generators of power and energy are noted and discussed in this section.

A. Many Potential Applications. A trump card for projected LENR generators is that they will be useful for many applications. The needs for hot air and water, and for electricity are very widespread in homes, offices, and factories. It is not necessary to recite all of the uses of thermal energy and electricity. Extensive lists have already been published by Defkalion and others. However, there are two possible applications of LENR generators that will have immense benefits, the local generation of electricity and the production of healthy water. So, these are noted here.

B. Proliferation of Electricity. Not long ago, over half of the people on earth had never talked on a telephone. The explosive adoption of cell phones is rapidly increasing the use of telecommunications in poorer as well as richer countries. Similarly, over one-third of the seven billion people in the world still lack electricity. If LENR electrical generators are affordable to the developing parts of the world, then those 2+ billion people could use technologies that require electricity, most notable computing and communications. The pervasive availability of computers and the internet would have dramatic impacts on education and, hence, economic productivity, not to mention greatly improved lifestyles and contentment.

C. Production of Clean Water. Humans need water on a frequent basis to sustain life. Roughly one billion people on earth do not have good drinking water now. The possibility of being able to produce drinkable water from dirty rivers and the seas using the heat from LENR would be momentous. It could turn out to be one of the main drivers for exporting LENR generators into what are called “third world” countries. Favorable pricing of LENR generators for such countries could conceivably contribute significantly to world peace. The situation might be similar to the current sales of medicines for AIDS to poor countries at reduced prices. Rich countries will not soon give poor countries a large fraction of their wealth. However, they could provide some of the energy needed for development and local wealth production at discounted prices, while still making money from manufacturing LENR energy generators.

D. Global Medical Impacts. The availability of water free of pathogens and parasites to a very large number of people should lead to dramatic reductions of the incidence of many diseases. Worldwide, 20% of the deaths of children under five are due to diseases related to poor water [3]. The savings of lives, human suffering and costs of medical assistance, where it is available, might greatly outweigh the cost of buying and using LENR generators. The better availability of electricity would improve both the diagnostic and therapeutic sides of clinical medicine.

E. Fewer Environmental Impacts. The favorable characteristics of LENR generators relative to the effects on the environment of their fabrication, operation and disposal were already noted above. But, it is worth summarizing them because of their significance. The production of LENR generators could produce less environmental degradation than the manufacturing of cars or other large-volume consumer products. Their operation will not produce air pollution, greenhouse gasses or other emissions, such as dangerous radiations. The wide adoption of LENR technologies will not, by itself, solve the climate change problem. But, it could slow the increase in global temperatures and, thereby, ameliorate the already clear and devastating effects of global warming. LENR generators will leave behind no significant radioactive waste, and can be recycled as is increasingly normal for consumer goods. So, their overall effect on the environment might be strongly positive.

F. Global Economic Shifts. If the use of LENR generators approaches the possibilities now contemplated by some people, there might be dramatic economic changes in the world as we know it today. There could be new economic paradigms on levels ranging from the personal to organizational to national to regional to global. If individuals were able to spend dramatically less on energy, money would be freed for other expenditures and for investments. Existing industries could redeploy capital from energy to use of newer technologies. More energy intensive industries might become viable. Nations that now get a large fraction of their energy from abroad might be able to afford better education or medical care. Transportation costs might decrease at all levels. The sum of the potential impacts on many levels would change the economic world as it now exists.

G. Global Political Changes. If the dominant source of energy in the world did not depend on the vagaries of geology, but on the technology and manufacturing prowess of any (or many) advanced nations, the world could have a new political paradigm. Greater efficiencies of production of goods and delivery of services in the advanced countries would be a "game changer". Peoples and nations that have not enjoyed the benefits of modern technologies could begin to do so, and gain hope in the process. Healthier and more capable people could do more and accelerate globalization of good conditions, the so-called "flattening" of the earth.

H. New Field of Science. The points and comments above are based on the possibility that viable commercial LENR generators will be sold and used, maybe even before the mechanisms in the units are adequately understood. Such a situation has precedents. X-rays were discovered in 1895 and put to almost immediate use, long before even the nature of atoms and their electron energy levels were adequately understood. Superconductivity was discovered in 1911, and could be demonstrated and put to limited uses before it was understood about four decades later. If the production and delivery of commercial LENR units happen, as hoped, in 2013 and in the immediately following years, funding for the study of the science of LENR will follow. The situation might be like that for nanotechnology. In five years around the beginning of this millennium, global funding for nano-science and nano–engineering increased fivefold, leading to many product improvements and new products. If that happens, and LENR are understood and thoroughly explored, the new knowledge will probably accelerate the optimization of practical LENR generators. Improvements in controllability and reliability will be especially desirable.

5. CONCLUSION

There are various ways for several of the prospects presented here to fail to materialize, at least initially. One of the more likely possibilities is for LENR energy generators, even though they work initially, to be unreliable. Long-term operation is fundamental to the commercial success of the new technologies. The envisioned commercial systems necessarily involve tightly integrated technologies. They include electrical, mechanical, thermal and fluidic sub-systems, all of which depend on materials properties. There are many potential failure modes.

There is also the possibility that LENR generators will work well and reliably, but suffer public perception problems. Having the "N word" nuclear in the title of the technologies might lead to public fear, which will at least slow adoption of LENR energy generators. Again, medical diagnostic imagers based on Nuclear Magnetic Resonance were termed Magnetic Resonance Imagers because of the widespread fear of things nuclear. It is also possible that the high performance and favorable economics of LENR generators will lead to their rapid and widespread adoption. Still, early adoption of a new name for the reactions occurring in LENR experiments could be beneficial to early commercialization of power and energy generators based on such reactions.

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1 “Electrochemically Induced Nuclear Fusion of Deuterium“, J. of Electroanalytical Chemistry, vol. 261, 301-308 (1989).

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3 http://thewaterproject.org/

Possibilities and Challenges for Commercial LENR Energy Generators

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CEO

ILENRS-12

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Agenda

Potential Advantages

Challenges

Potential Impacts

Conclusion

Potential Advantages

High Energy Gains
Sustained ("Burning") Reactions
Production of Heat
Generation of Electricity
Opportunities for Optimization
Safe Operation
Fail Safe Operation
Radiation Safety
No Input Radioactive Materials
Adequately Safe Input Chemicals
Beneficial Waste
No Radioactive Waste
No Chemically Dangerous Waste
No Greenhouse Gas Emission
Silent Operation
High Energy Density
Lightweight Systems
Portable Energy Systems

Scalability (Diverse Power Levels)
Low Capital Cost
Low Operational Cost
Easy Operation and Refueling
Long Times Between Refueling
Long Operational Lifetime
Abundant Hydrogen Fuel
Abundant Nickel Fuel
Low Cost Power: 5 cents….$100+
Distributed LENR Generators
Relief for the Power Grid
Fewer Large Power Stations
Easy Disposal of LENR Generators
Rapid Adoption Once on the Market
Many Potential Applications
Proliferation of Electricity
Production of Clean Water

http://www.infinite-energy.com/images/pdfs/NagelIE103.pdf

Advantages: Performance

High Energy Gains

Sustained ("Burning") Reactions

Production of Heat

Generation of Electricity

High and Versatile Performance

Advantages: Cost

Low Capital Cost

Low Operational Cost

Low Cost for Refueling

Long Operational Lifetime

Potential for Rapid Adoption

Purchase, Operation and Maintenance are all Low Cost

Advantages: Money Gain

The 1.25 grams of Nickel in a US 5 cent coin, if completely reacted to Copper, would produce the energy equivalent of a barrel of oil.

$ 0.05

$ 100.00

Remarkable Financial Leverage

Advantages: Operation

Little Training Needed

Silent Operation

Easy Operation and Refueling

Long Times Between Refueling

May be as User-Friendly as Indoor Plumbing

Advantages: Safety

Safe Operation

Fail-Safety

Easily Shielded Radiation

Safe Input Chemicals

No Radioactive Input

No Radioactive Waste

Potentially Very Safe

Advantages: Environmentally Friendly

No Greenhouse Gas Emission

No Chemically Dangerous Waste

Potentially Beneficial Waste

Easy Disposal of Used Generators

Abundant Fuels: Hydrogen and Nickel

Very Environmentally Friendly

Advantages: High Power Density

Small Size

Lightweight

Distributed Power Sources

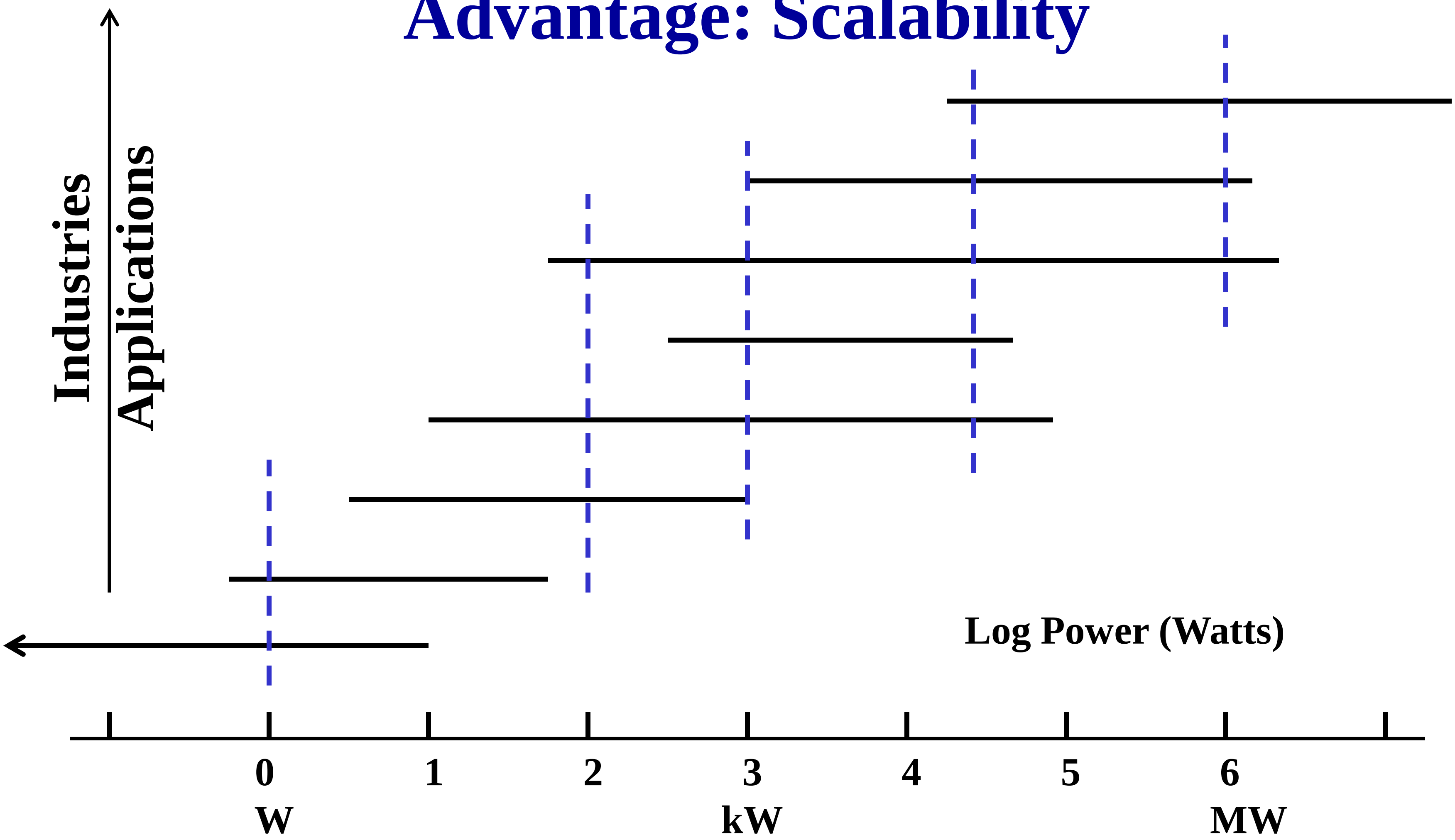
Fewer Large Power Stations

Relief of the Grid

Portability

Game-Changing Possibilities

Advantage: Scalability



Hundreds (maybe Thousands) of Potential Applications

Challenges

Engineering	**Producing products is difficult**
Reproducibility	**Operation must be the consistent**
Controllability	**Speed and degree of control are critical**
Reliability	**LENR generators must respond as desired**
Durability	**Lifetime of LENR generators is important**
Safety	**Looks good, but…..??**
Regulations	**Untested and unknown now**
Perceptions	**Public aversion to the word “nuclear”**

Challenge: Engineering

Design, manufacture and testing are all unavoidably necessary.

Complex simulation software, such as ANSYS, must be applied to the design of LENR generators.

Manufacturing and testing might re fairly straightforward

There is a great deal of experience on steam generation, but there is less knowledge for kilowatt level generators.

Electrical generators are quite common consumer products, but they are based on gasoline engines.

5.5 kW

Challenge: Reproducibility

Reproducibility problems have plagued LENR experiments.

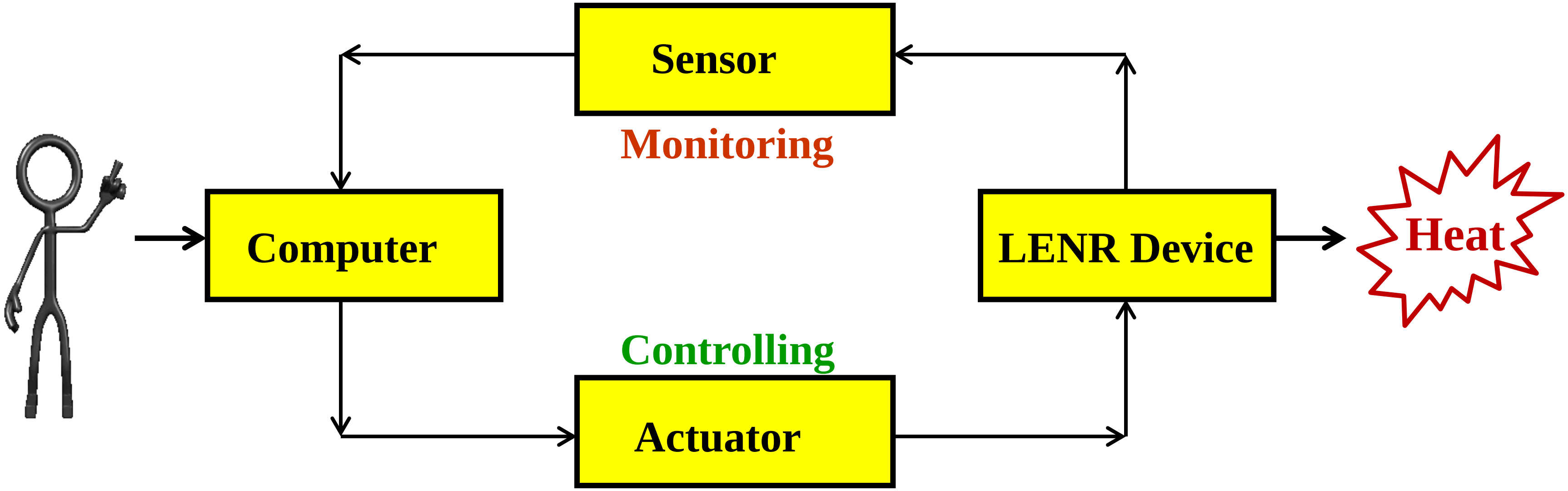
Such problems are still not generally under control.

It is probable that some yet-unknown materials variable as at the core of past and current reproducibility problems.

That might mean that the materials used in commercial LENR power generators might have to be tightly controlled in either or both composition and structure.

The need for precision materials might drive up the costs of fueling LENR generators.

Challenge: Controllability



What are the control parameters?
What actuators are effective?
What sensors are needed?
What are the response times?
How stable is the output power?

Challenge: Reliability

Reliability deals with the consistency of the output heat or electricity for the same control parameters.

The reliability of LENR generators is (a) unknown and (b) very critical to their commercial success.

How much variation in the output hot water is needed for routine consumer uses? Consider a shower.

Will an additional temperature control systems be needed for industrial processes?

How much variation in the electrical output is tolerable?

Will it be necessary to have the LENR electrical generator integrated with the grid as a backup for uninterrupted power?

Challenge: Durability

For LENR thermal and electrical generators to penetrate a large fraction of homes, first in developed countries, they must have usefully long lifetimes.

Even if LENR generators are relative cheap and very cost-effective, replacing them is a hassle.

Consider current home hot water heaters and HVAC units.

Possible, electrical generators will fail first, with control systems being the next weakest part of a LENR generator.

If surface reactions are dominant for LENR, then maintenance of proper surfaces is a central practical problem. Control of impurities in LENR generators could be challenging.

Challenge: Safety

It appears that the routine operation of LENR generators can be safe and also fail-safe.

Radiation safety does not seem likely to be problematic.

High temperatures can be safety problems, for example, loss of insulation and contact with flammable materials.

High pressures, especially in steam lines, can lead to problems.

For units with integrated electrical generators, there are the mundane problems of electrical safety.

Challenge: Regulation(s)

Governments are various levels regulate consumer products, especially those that might involve safety.

National, state and even local jurisdictions might get involved.

A few accidents, even if incidental, would attract attention

Challenge: Public Perceptions

The public remains ignorant and fearful of things nuclear.

The imaging technique NMR went to market as MRI.

Might have to drop LENR for something more acceptable.

Steps from Concept to Commerce and Beyond

Concept: Prototype or Product
Goals: Requirements and Specifications
Design: Geometries and Materials
Modeling: How Does the Model Perform?
Parts: Procurement and Fabrication
Assembly: Modules and Systems
Testing: Performance and Reliability

Regulatory Approval (and UL certification?)
Distribution and Sales: Many Options
Customer Service is Critical

Optimization: Performance, Cost, Etc.

Maintenance and End-of-Life Considerations

Impacts: Many Potential Applications

Production of Clean Water

Historical Medical Improvements

Proliferation of Electricity

Lifestyle Improvements

Better Education

Very Widely Useful,
Both Functionally and Geographically

Clean Water !!!

Distributed LENR thermal generators might be used to provide clean water by either desalination or clean up of dirty river or lake waters.

The global health impacts could be historic.

Other Potential Impacts

Global Medical Impacts

Lessened Environmental Impacts

Global Economic Shifts

Power and Political Changes

Increased Scientific Research

Now, all of these are
HIGHLY UNCERTAIN !!

Conclusion

Scientific advances are critical to all aspects of the field.

Engineering is in an early stage of development and still crude.

Business on a large scale (numbers and $$$$) has not begun.

Current Bottom Line

LENR generators of heat and electricity are very promising, and the current global excitement is understandable.

HOWEVER, there are MANY steps that must ALL work for LENR to be widely used and have dramatic impacts.