Potential Advantages and Impacts of LENR Generators of Thermal and Electrical Power and Energy

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Many lists give the possible performance and implications of systems which use LENR for generation of thermal or electrical power. They mostly reside at various places on the internet. This paper brings together in one location and in written form the separate, though often related, items from the lists of possible positive features and future importance of LENR generators of power and energy. Some comments are provided on each of the putative advantages and impacts in the following pages.

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. Also, it is recognized that this list is despised by critics, who scorn even the existence, let alone the practicality, of LENR. Both the lack of any validated theory to explain LENR, and what seem to be overly-optimistic views of LENR applications, offend many commentators. Absence of scientific understanding is one thing. A set of potential properties that seems too good to be true is something else. The following compilation deals with, and possibly contributes to, the second of these perceived problems with LENR.

Years from now it will be interesting to see how many of the following prospects have been realized. Will the current hype over the potential of LENR generators be validated? 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, not to be reliable. 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. Recall that medical diagnostic imagers based on nuclear magnetic resonance were termed magnetic resonance imagers (MRI) because of the widespread ignorance and fear of things nuclear. However, it is also possible that the high performance and favorable economics of LENR generators will lead to their rapid and widespread adoption. This could occur at a particularly opportune time in world history. The urgent need for new and better sources of energy is widely recognized. Listing and discussion of the potential advantages and hypothetical beneficial impacts of LENR energy sources follow.

High Energy Gains

Energy gains are defined as the ratio of energy out of a system to the input energy required to operate it. If it is possible to use chemical energies on the order of electron volts to initiate nuclear reactions that generate millions of electron volts, enormous energy gains might be possible. 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 gaseous H-Ni system. For comparison, the International Thermonuclear Experimental Reactor (ITER), a hot fusion experiment being built in southern France at a cost exceeding $20B, is seeking an electrical-to-thermal energy gain of 10 during the 20+ year project. It must be noted that some experimenters report the Coefficient of Performance (COP) for LENR generators. COP = [(Energy Out) minus (Energy In)] divided by (Energy In). For high values, the COP is approximately equal to the energy gain ratio.

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. Rossi has asserted that, once started by heating due to electrical power input, some of his LENR devices have continued to produce energy after the input power is turned off. Such sustained operation can lead to enormous energy gains, since the output energy continues to increase without increase in the input energy.

Production of Heat

The raw output of LENR generators is thermal energy, which can be used to raise the temperature of diverse working fluids. In the simplest embodiment, a single-pass stream of gas or liquid will be heated. For some applications, there will be a primary loop in which the working fluid is circulated. In such cases, that loop will deliver the thermal energy to a device that uses it. In others, the primary loop will carry energy to a heat exchanger that will heat gasses, notably air, or liquids, often water. For either mode, the production of thermal energy for homes, offices and factories will be a primary function of 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. Thermal-to-electrical power conversion efficiencies would be roughly 30%. 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. One great goal is the development of solid-state refrigeration units. The advancement of thermoelectric materials is challenging because they must conduct electricity efficiently but have low conductivities for heat. Other devices, such as micro-gap thermo photovoltaics, are also under development to convert thermal energy to DC electricity without the use of rotating machinery. Available inverter technologies can be used to produce AC from the DC coming from LENR devices, which are integrated with direct thermal-to-electrical transducers.

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. Automobiles, computers and cell phones are familiar examples. The point is that the production and use of LENR thermal and electrical generators are now in the earliest stages of commercialization. While near-term LENR systems should be useful—as were cars a century ago, personal computers in the 1980s and cell phones in the 1990s—one of the expected advantages is their future improvements. Optimization of manufacturing processes, which will lower costs of LENR generators, can also be expected.

Safe Operation

The safety of power sources and energy transduction devices is an enduring concern. Boiler explosions were common in the 19th century and led to stringent safety codes. Gasoline fires provide another example of concerns over the safety of high energy density materials. 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. So, 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. Nothing definitive seems to be published on any instabilities or run-away events for LENR devices operated at energy gains of 100 or higher. Sometime in the future, organizations concerned with safe operation of LENR generators might perform tests in which units with various energy gains are permitted to run-away in order to determine the scaling of safety thresholds. It might turn out that catastrophic runaways are not possible, that is, the reactors shut themselves down before causing problems other than their own inoperability.

Fail Safe Operation

The control of the output of any power source is a necessary concern. It would be nice if LENR sources had the same kind of control as automobile engines. In cars, power production can be initiated, turned up, maintained stable, turned down and switched off at will with very short lags between control actions and generator responses. It appears that LENR power sources will not offer such near-instantaneous responses. However, 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 shutdown energy production. Operation of Rossi's Energy Catalyzer (E-Cat) devices requires powdered nickel, which would not remain in the required form for long at very high temperatures. Hence, properly designed LENR generators, made of refractory alloys, would not melt down as do failed fission reactors, most recently in Fukushima. This is a particularly attractive feature of LENR energy sources, which might be used by a wide variety of ordinary individuals. Fail-safe operation, while expected, still demands clear demonstrations by use of LENR sources that are to be sold.

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Radiation Safety

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. By contrast, nuclear energy power sources, which are inherently radioactive, can be made to operate safely, even though fission and hypothesized hot fusion sources unavoidably emit significant amounts of prompt radiations dangerous to humans. Protection from energetic neutrons and from gamma rays emitted by nuclear power sources requires thick hydrogenous and other shielding for neutrons and high atomic number shielding for gamma rays. 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.

No Input Radioactive Materials

The fuel for current and prospective fission reactors is at least somewhat radioactive, and sometimes generates concerns about nuclear proliferation. That requires extensive and expensive procedures for safe processing, fabrication, transportation, storage and other handling. Commercial hot fusion reactors, which might be demonstrated about the middle of this century, would use tritium as one of the fuels. Tritium is an expensive radioactive gas, the handling of which also requires stern safety measures. The input fuels for current experimental and possible near-term commercial LENR power and energy generators are benign. They are available on the market now, although mixing and other pre-processing for their activation might be needed.

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. Those pressures definitely present challenges for safe operation. But, it should be noted that such pressures are not uncommon in industrial processes. Pressures in SCUBA tanks, often used by diverse and poorly-trained vacationers, range up to 3000 psi, that is, well over 200 atmospheres. Of course, hydrogen is much more of a safety problem than air. It is combustible, burns without a visible flame and can lead to embrittlement and failure of metals. However, there is a long history of handling pressurized hydrogen in chemical processing industries. And, the use of hydrogen in vehicles can also be done safely. Tanks within hydrogen filling stations and vehicles have pressures in the 350 to 700 atmosphere range. 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) throughout the world.

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, generally from unknown species with unmeasured energies. However, radioactive waste now appears not to be a problem for LENR energy sources.

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. Currently, nickel is about 2.5 times as expensive as copper, so money will not be made on a per-pound basis by turning nickel into copper. However, retrieving the copper from LENR generators might be cheaper than mining and refining copper ore.

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 thousands of years. The operation of hypothetical hot fusion reactors would also result in radioactive materials. One of the touted advantages of hot fusion reactors is that their waste would be dangerous for only a few centuries. 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, generally from unknown species with unmeasured energies. However, radioactive waste now appears not to be a problem for LENR energy sources.

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 produce excess energy. However, the residues from early commercial LENR generators need to be subjected to careful chemical analyses to verify that their operation produces no dangerous residual chemicals.

No Greenhouse Gas Emission

Electrochemical LENR experiments evolve oxygen, which is naturally safe, and sometimes hydrogen or deuterium gas, which is explosive when mixed with oxygen. Unreacted hydrogen or deuterium can be recombined with oxygen to produce ordinary or heavy water by use of a catalytic material. When it works, the recombiner solves the potential problem of (usually small) explosions due to reaction of hydrogen and oxygen. But, recombiners can become poisoned, so it seems that there is a need to effectively engineer electrochemical LENR cells to make very unlikely any conceivable explosive problems. However, it is highly probable that LENR generators in the near-term and, probably, long-term will not employ electrochemical means to bring together hydrogen isotopes with metals. The gas loading of protons onto and into nickel is the preferred approach commercially, for simplicity and because that approach reportedly yields high output powers. In the gas loading approach, closed containers are used, so barring an accident, there is essentially no possibility of the release of any gases, let alone the greenhouse gases such as carbon dioxide. As already noted, it is possible to engineer gas loading LENR devices so that the risk of their rupture during service is very low. LENR electrochemical experiments and gas loaded generators have not been shown to produce greenhouse gases during or after the operation of excess heat experiments to date.

Silent Operation

One of the standout characteristics of LENR power sources is the near 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. The pumps that move the working fluid through primary or secondary cooling loops necessarily make some sounds, especially if reciprocating pumps are used. But, the employment of impeller and other types of rotary pumps is relatively quiet. The low levels of noise from LENR generators are important if they will, as expected, be used in homes and factories. To appreciate the value of silent operation, consider the noise made by conventional electricity generators that have gasoline engines. Their exhaust is also problematic.

High Energy Density

The density of power and energy in sources of heat or electricity are important parameters. Batteries, for example, are rated in milliamp-hours per liter or kilogram. mA-Hrs is a measure of the number of electrons stored in a battery. Given the known voltage of a battery, mA-Hrs are easily converted to electron volts, a measure of energy. Clearly, high energy density is significant for portable electronics. Batteries, notably those with Li ion chemistry, pack relatively high numbers of electrons and the associated energy into small volumes. That enables long run times between charging. As with batteries, 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 1 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. Some people have even contemplated LENR sources being used in personal electronics. That is not a near-term likelihood, if it ever happens. Early commercial multi-kilowatt LENR systems are projected to have volumes that might range from less than 1 liter to several tens of liters.

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. Of course, megawatt systems consisting of a hundred or more of the smaller units would require a fork lift or crane for their movement and placement. Multi-megawatt units would have to be built and operated in place. Floor loading considerations come into play for the larger units.

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. The early products now being developed by Leonardo and Defkalion are not powerful enough for ordinary vehicles. A car rated at 100 horsepower can generate mechanical powers of about 75 kilowatts. So, while portability of few kilowatt LENR generators might have some importance, powering of vehicles is not a near-term expectation. Long (>1 sec) lags between control actions and system responses are a critical consideration for transportation applications.

Scalability

Generators for electricity have been made for widely diverse power levels, ranging from a few watts for hand powered units to multi-megawatt units in hydroelectric power plants. That flexibility is achieved by design of generators for different power levels to fit application requirements or the availability of mechanical power. 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 long 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 small systems with tens or hundreds of kilowatts thermal output appears feasible. The limit on the number of units which can be ganged into a single power system is determined by the complexity of the electrical sub-system for control sensors and power input, and the fluidic sub-system, for which large numbers of connections make leaks more probable. 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 varying over six orders of magnitude. Sub-units with powers below one kilowatt are not now in sight commercially.

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 late 2012 and 2013. Defkalion has not yet commented on costs for their projected 5-45 kW units. However, Rossi has stated that he expects the cost for his few kW units to be about $50 per kilowatt. Such prices would put LENR generators within the reach of most owners of homes and small buildings. That would make them attractive to many, even if their cost of producing power were similar to the prices now paid for power from central power stations.

Low Operational Cost

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. That might be due to lack of information or a rosy expectation that units will be so cheap that they can be discarded rather than repaired. Such a situation might be like an ink jet printer, where the desktop device is very inexpensive because the printer companies make their money by selling ink cartridges. But, if refueling costs only $10, companies making LENR generators will have to gain a substantial fraction of their profits from initial unit sales. The question of the economics of LENR generators is not as complex as technical questions about their operations. However, the financial questions are as wide open as are the technical questions at present.

Easy Operation and Refueling

The units now planned for the market apparently will require 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. If LENR generators run best at constant output, there are two possibilities. They could be operated at peak power outputs, and means to discard unused heat made part of the system. That would exacerbate global warming. Or, the units could be run at an intermediate level and extra energy from low-use times might be stored for later use during peak requirements. The ongoing development of means to store energy for solar and other unsteady sources of energy might prove useful for storage of

LENR energy. Rossi asserts that the E-Cat devices can be refueled simply, even by capable homeowners. That is, it may not be necessary to call in trained service personnel for refueling. However, even if technicians are needed, the situation would be similar to how people care for home heating units now.

Long Times Between Refueling

The currently projected time of six months between refueling of E-Cat systems might not seem very long. But, it is long compared to the time for refueling generators that burn hydrocarbons. And, it must be remembered that the period of six months assumes constant operation. Shorter duty cycles will permit longer times between refueling. For example, a 50% duty cycle could lead to one year before insertion of fresh fuel into a LENR power generator.

Long Operational Lifetime

The LENR generators now being planned for sale are relatively simple devices. They do require pumps, 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. Gasoline powered generators would wear out much sooner, if they were operated continuously. Both their motors and generators are rotating machines with bearings or other components that will fail before they can run continuously for decades. Of course, while the core LENR heat generator might last decades, any electrical generator it powers will not last as long. But, replacements should be possible, much as the internal components of a home heat pump can be replaced. If a home LENR unit costs, say, $300 and lasts for 30 years, the average annual capital cost would be substantially less than the price of one ticket to many movie theaters.

Abundant Hydrogen Fuel

Hydrogen is one of the most common elements on earth. Consider the oceans. Freeing hydrogen from water could be done electrolytically by using a small fraction of the energy produced by LENR generators. The fundamental numbers are very favorable. It costs 1.23 electron volts (eV) to disassociate water by electrolysis to produce hydrogen and oxygen gases, that is, H_2 and O_2. Then, 4.52 eV are needed to change the H_2 molecules into hydrogen atoms. And, 13.6 eV are needed to ionize one hydrogen atom to produce a proton and electron. The sum of these energies, namely 19.35 eV, gives the energy needed to start with water and produce a single proton. Production of protons from both of the hydrogen atoms requires 32.95 eV or an average of 16.47 eV per proton. If both protons react with nickel atoms to produce copper atoms, 2 x 7.85 MeV are liberated in the two identical nuclear reactions. Hence, only 16.5 eV out of 7.85 MeV, or 2 ppm of the liberated energy, are needed to produce the hydrogen fuel by electrolysis. Of course, it will cost energy to compress, store, handle and otherwise manipulate hydrogen prior to LENR reactions. But, 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.

Ample Nickel Fuel

Nickel is the 24th most abundant element in the earth's crust. About 1.3 million tons of nickel are mined annually. One percent of that amount would be equivalent to 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. The International Nickel Study Group estimated that, at the present mining rate, there is enough nickel on the land to last a century, not counting LENR. Nickel in seawater has a concentration of 1.7 micrograms per liter. Some research on its extraction has been done. Reports of energy generation with materials other than nickel have appeared. Hence, fuel economics for LENR generators are quite uncertain.

Low Cost Power

Here also, it is hard to be confident about the overall costs 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 U.S. now. By itself, such performance would insure the widespread adoption of LENR sources of electrical power. The numbers for production of thermal energy using E-Cats are even more compelling. Rossi estimated that the amount of nickel in a U.S. five cent coin, that is, 1.25 grams, would produce energy equivalent to five barrels of oil. This author checked that computation and got 2.5 rather than 5 equivalent barrels. 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 for a LENR thermal source could be 20 x 100 = 2,000 times less, compared to oil. If this proved to be the case, then the availability of commercial LENR power will be remarkably "disruptive" to the global economic and political status.

Distributed LENR Generators

One of the greatest projected impacts of small, few kilowatt LENR generators of heat or electricity is the possibility that they will be in individual homes and other small buildings. Homeowners 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. That control naturally comes with the responsibility to keep the units in good operating condition. It would be much like the current use of automobiles. Drivers are responsible for insuring that they have adequate gasoline on board. 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.

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. About 6 to 8% of the electrical power generated in the U.S. never makes it to users. Given that there are about 100 nuclear and 600 coal-fired electrical power production stations in the country, those losses are equivalent to about 50 entire power stations. Most of the electrical power stations are now 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 sources located near the users of the power.

One of the advantages of LENR power generators is that they might be widely adopted very quickly. Usually, it takes roughly a decade or two for pervasive adoption of even the most popular technologies. . . 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. Already-available manufacturing processes will suffice for their production. Hence, emplacement of a large manufacturing infrastructure should be relatively cheap and fast. . .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.

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. LENR generators that cost a few thousand dollars and have lifetimes of a few decades are very attractive compared to nuclear and other central power stations. Giant stations have capital costs in the billion dollar range and must operate for about half a century.

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 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. At worst, it might be necessary to have dedicated means for the recycling of LENR units, much as electronics are now eCycled to insure that the materials in them do not pollute the environment. In any event, the end-of-life problems with LENR generators might be quite nominal, nothing remotely resembling the disposal of either fission or hypothesized hot fusion wastes or equipments.

Rapid Adoption

One of the advantages of LENR power generators is that they might be widely adopted very quickly. Usually, it takes roughly a decade or two for pervasive adoption of even the most popular technologies. Cell phones are a very recent example. 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. Already-available manufacturing processes will suffice for their production. Hence, emplacement of a large manufacturing infrastructure should be relatively cheap and fast. This prospect is in contrast to cell phones, for which many stringent advances in microelectronic engineering were needed to be able to produce the phones now on the market. 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.

Many Potential Applications

Another 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 ramifications of LENR generators that will have immense benefits, the local generation of electricity and the production of healthy water. So, these are noted here.

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 notably 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.

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 by 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. This is a historic opportunity.

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. The savings of lives, human suffering and costs of medical assistance, where it is available, might greatly outweigh the costs of buying and using LENR generators. The better availability of electricity would improve both the diagnostic and therapeutic sides of clinical medicine.

Fewer Environmental Impacts

The favorable characteristics of LENR generators, relative to the effects on the environment of their fabrication, operation and disposal, were already touched on above. But, it is worth summarizing them because of their significance. The production of LENR generators should produce no more 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 possibly 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.

If a major 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 see major power shifts and have a new political paradigm. Greater efficiencies for 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.

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 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 the 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 and improved medical care. Transportation costs might decrease at all levels. The sum of the potential impacts on many levels could change the world economy.

Power and Political Changes

If a major 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 see major power shifts and have a new political paradigm. Greater efficiencies for 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. Reduced strife is conceivable.

Increased Scientific Research

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 active 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 long before it was understood about four decades later. If the production and delivery of commercial LENR units happen as hoped, in late 2012 and 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 increased research 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. LENR are interesting and exciting in three arenas: science, engineering and commerce.

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