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Research Article

The Role of LENR in Keeping the Earth Habitable

Thomas W. Grimshaw and David J. Nagel
LENRGY, LLC, Austin, TX and NUCAT Energy, LLC, Falls Church, VA

Abstract

Science and technology have been a boon to humankind and have greatly increased the human carrying capacity of the earth. Their requirements for huge quantities of energy, and reliance on fossil fuels for the supply, have long been a problem for the environment. Now, because of global climate change (GCC), the effects of Science and Technology constitute a threat to the very habitability of the earth. The cold fusion announcement in 1989 came very soon after the many laws and regulations worldwide came into effect to protect the environment starting about in the 1970s. Unfortunately, instead of being pursued for its energy benefits to respond to the impacts of fossil fuels, cold fusion (now often referred to as low energy nuclear reaction, LENR) was rejected by mainstream science. Now more than 30 years after the announcement, LENR energy is needed more than ever to mitigate GCC and its impacts. LENR can also ameliorate the effects of centuries-long use of fossil fuels and their environmental effects. Many factors influence how LENR will be able to displace fossil fuels. Perhaps the most important factor is reversal of current negative public policies for LENR research and development support. Much greater investment is needed to resolve issues of inadequate experimental reproducibility and thorough theoretical understanding. Other factors are the quality (temperature) of produced energy, the amount of required input energy to reactors, suitability for different energy end use sectors (including transportation), and the percentage of total fossil fuel consumption by the different end use sectors being displaced. Besides fossil fuel displacement, LENR energy will be very useful to deal with the now-inevitable GCC impacts and needed responses to the effects of past and continued uses fossil fuels. To reduce the carbon dioxide content of the atmosphere, LENR energy may be used to remove it from the atmosphere directly or by taking it out of the flue gas of fossil fuel power plants. LENR energy may become important for dealing with large-scale GCC effects, such as sea level rise, more intense storms, coastal erosion, wildfires and air pollution, and changes in water availability and use. Because of the very large numbers of locations of fossil fuel facilities and their impacts around the world, LENR energy will be needed for cleanup operations for decades to come. Another application of LENR energy will be to power pollution control technologies, such as sulfur dioxide scrubbers at power plants, for the expected long transition from fossil fuels to LENR energy.

Keywords: LENR Energy, Fossil Fuel Replacement, LENR for GCC Impacts, LENR for Survival of Humankind.

1. Introduction

It is generally accepted that the earth is experiencing a human population explosion. It got underway about 1950, when the population was about 2.5 billion. Global population now stands at over eight billion. The human carrying capacity of the earth would have been exceeded long ago if it were not for two related factors – Science and Technology on one hand and massive increases in energy generation and consumption on the other.

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The increasing energy demands of modern societies have been met almost entirely by burning fossil fuels, coal, petroleum and natural gas, which has released large quantities of carbon dioxide into the atmosphere. Because of the greenhouse effect, the carbon dioxide, along with methane and a few other gases, are causing global climate change (GCC). The potential consequences of releasing large quantities of carbon dioxide on the earth's climate was described as early as 1896 in a climate model constructed by Svante Arrhenius [1]. Worldwide concern about GCC resulted in the creation in 1988 of the Intergovernmental Panel on Climate Change (IPCC) [2], which has prepared forecasts of climate change and mitigative measures.

The climate change crisis was preceded by a long history of environmental impacts of fossil fuel combustion and associated industrial activities at or near the earth's surface. Whereas the response to GCC effects came to the fore in the 1980s, the near-surface impacts were addressed starting 10 years earlier. The decade of the 1970s, termed the "Decade of the Environment", saw development of many laws and regulations to protect the air, water and other natural resources.

In a similar timeframe, cold fusion was announced in 1989 by Martin Fleischmann and Stanley Pons at the University of Utah as a potential new source of energy [3]. It could not only replace fossil fuels, but also supply energy for dealing with the effects of GCC as well as long-standing fossil fuel environmental impacts. Unfortunately, cold fusion (now frequently referred to as low energy nuclear reaction, LENR) was rejected by mainstream science within a year or so.

Despite the rejection, LENR continued to be pursued by a worldwide group of highly qualified scientists from many different disciplines. They have produced over five thousand papers and held 25 international conferences since 1989. The growing evidence in favor of LENR indicates that it might yet realize its potential as a revolutionary new energy source. If so, LENR could be yet another example of the role of Science and Technology increasing the earth's human carrying capacity.

2. Fossil Fuels – the Underbelly of Science and Technology Benefits

Science and technology have unequivocally contributed many benefits to humanity and extended the human carrying capacity of the earth. A large fraction of these contributions relies on energy for realizing their benefits. A primary example is transportation in all its forms, autos and trucks, railroads, ships, and aircraft, all of which owe their development to technological innovations, and all of which require large quantities of concentrated energy. Another example is electrical power, which has contributed to human benefit by technological developments in generation, distribution and consumption.

It is unfortunate, perhaps even tragic, that new sources of energy without greenhouse gas or the emissions and effluents of fossil fuels have not kept pace with technical developments of energy consuming applications. The early rejection of LENR before it could be diligently pursued for human benefit was a major expression of this tragedy. On the other hand, the dedicated pursuit of LENR by a small but very active group of researchers has produced evidence of substantial energy benefits that may yet be realized.

3. The Timely Emergence of Low Energy Nuclear Reactions

LENR was announced in 1989 by Martin Fleischmann and Stanley Pons [4]. Now, more than 30 years since it was announced, LENR is still being pursued for resolution of its issues of inadequate understanding and lack of reliable reproducibility.

3.1. Announcement and Rejection

Nevertheless, LENR continues to be pursued by many highly qualified researchers both for its intrinsic scientific appeal and its possibilities as a new clean energy source. Experiments have indicated that LENR involves hydrogen (isotopes protium and deuterium) interacting within a metal lattice, particularly palladium or nickel. The reaction results in energy (in the form of heat), helium, particle and electromagnetic radiation, and elemental transmutation. The amount of energy released is very large, much larger than can be produced by any known chemical reaction.

Fleischmann was a noted researcher in electrochemistry, who became a Fellow of the Royal Society as the result of his work in that field. He was born in 1927 in Czechoslovakia, but his family immigrated to England in 1938 to avoid Nazi persecution of Jews. He received his doctorate at Imperial College London in 1951 with a thesis on the diffusion of electrogenerated hydrogen through palladium foils. In 1967, he became a professor of electrochemistry, occupying the Faraday Chair of Electrochemistry at the University of Southampton, where he remained until retirement in 1983.

Dr. Stanley Pons was born in 1943 in North Carolina. After starting his Ph.D. at the University of Michigan, he changed to the University of Southampton, where he received the degree in 1978. He met Martin Fleischmann there in 1975. Fleischmann and Pons apparently began collaborating on research on the possibility of energy from electrolysis sometime after Fleishmann's 1983 retirement. The collaboration included visits to Pons by Fleischmann while the former was on the chemistry faculty at the University of Utah.

When LENR was discovered, interactions with Stephen Jones at Brigham Young University resulted in Fleischmann and Pons' decision to make their LENR claim by a press conference in March 1989. The conference was immediately followed by a guided tour of their lab by members of the press. The Fleischmann-Pons paper on the announced work was published soon after the press conference [5].

The potential for energy production from LENR was widely realized at the time. For example, during the press conference, Stanley Pons said the following in response to a question:

> Well, we've been concerned primarily with the effect – the observation of the fusion event. I would think that it would be reasonable within a short number of years to build a fully operational device that could drive – produce electric power or to drive a steam generator or a steam turbine, for instance.

The good news of the potential solution to the world's energy needs was welcomed around the globe [6], [7]. However, the issues of insufficient reproducibility and the challenge of developing a scientific explanation soon came to the fore. LENR was in fact rejected from mainstream science within less than a year after the press conference. The sequence of events in the rejection is well described in several published works [8], [9]. The scientific rejection in turn led to public policy decisions to devote little research funding for pursuing LENR and its energy benefits.

3.2. LENR Energy Advantages

Initially, LENR energy was viewed mostly as a potential supplement to fossil fuels, which were perceived to be on the brink of exhaustion. Memories were still vivid about energy shortages and long gas lines during the oil embargoes in the 1970s. With growing awareness of the GCC crisis, greater emphasis is now on LENR's potential to totally displace fossil fuels. In addition to such displacement, LENR energy offers a number of advantages over fossil fuels:

- Relatively less expensive
- Virtually unlimited supply
- Clean: no emissions or effluents
- Safe: no radiation or radioactive waste
- High energy return: output versus input
- High energy density
- Flexible: possible centralized or distributed deployment
- Low cost of materials
- Operational advantages: low maintenance

These benefits are on top of (or a part of) the basic requirement of displacing fossil fuels and their GHG emissions.

3.3. Sequence of Development and Availability

When revolutionary new technologies like LENR are introduced, their applications typically are limited at first, followed with improvements and additional uses over time. Automobiles and airplanes are examples of limited uses initially, followed by major improvements and applications in the decades after introduction. When the issue of reliable reproducibility has been resolved, LENR energy applications will likely be limited, such as heating water below the boiling point, depending on the type of LENR device. With additional time and technology development, both the temperature and quality of energy from LENR may be expected to increase. Then, electrical generation using LENR energy might become common.

On the other hand, the GCC crisis may provide the impetus for faster development of the LENR reactors, particularly for displacement of fossil fuels. The rate of LENR energy availability is difficult to estimate, but it is posited here that the full range of applications will take place in a timeframe of one or two rather than many decades. It is also proposed that as improved reactors become available, the configuration at each stage of development may be either centralized or distributed. The advantages of distributed configurations, such as elimination of grid loss, is not addressed here.

4. LENR Energy for Displacement of Fossil Fuels

The extent to which and the timing of LENR energy displacement of fossil fuels depend on three primary factors: 1) the quality (temperature) of the produced energy; 2) the types of fossil energy being displaced for various end-use categories; and 3) the amount of resources and priority dedicated to resolving LENR's issues. The third factor has to do with public policies for the pursuit of LENR and dealing with its disruptive impacts. It is addressed in the next section of this paper.

4.1. Energy Capabilities

The European Union's Clean HME (for Hydrogen Metal Energy) has done a preliminary analysis of the potential for LENR energy to meet the needs of principal end-use categories [10]. Four categories of the quality of produced energy are recognized (the term "grade" is used here) as follows:

Grade 1. >300° C
Grade 2. Between 200° and 300° C
Grade 3. Between 100° and 200° C
Grade 4. < 100° C.

The HME analysis considers four types of LENR heat generators:

Type 1. Energy excitation from heat is required (with adequate insulation, Type 1 becomes Type 2.)
Type 2. Energy excitation is needed, but not from heat.
Type 3. Self-sustaining. Energy for excitation is supplied by produced energy (energy feedback).
Type 4. Self-sustaining with solid-state technology (not included in the scope of the study).

Types 1, 2 and 3 are reviewed for potential application based on the grade of heat they require (Figure 1). In general, the applications increase for the reactor types having the higher grade of produced heat.

4.2. Fossil Fuel Displacement by End-Use Sector

The EU study goes a step further and uses Figure 1 to evaluate LENR applicability to principal end-use sectors. The evaluation resulted in a diagram with axes for amount of energy required to be produced (heat input), grade of energy,

HME temperature:	< 100°C	<200°C	< 300°C	> 300°C
TYPE 1	Residential heating x 10^7 units kW	Commercial & industrial heating x 10^5 units 100_S kW		
TYPE 2	Residential heating x 10^8 units kW	Low pressure Boilers x 10^6 units 100_S kW -MW	High pressure boilers x 10^5 units 100_S kW -MW	Process heat x 10^4 units 100_S kW -MW
TYPE 3		Autonomous systems x 10^6 units 100_S kW -MW	Steam turbines x 10^5 units 100_S kW -MW	Power generators x 10^9 units kW - MW

Figure 1. LENR Energy Utilization Depends on Temperature (Grade) of Energy Production.

and end user sectors (including the number of units deployed) (Figure 2). The horizontal heat input axis refers to input of energy for the end use category, which translates into required output from the energy source. Therefore, the term "heat input" in the figure is referenced as "heat output" in this paper.

The study includes residential, commercial, transportation, and power categories. Although it does not specifically address the traditional industrial category, the study does include three of its main components, boilers, steel making, and liquefaction of natural gas. For this paper the boilers are assumed to be representative of the industrial sector.

The EU study provides several observations about how the types of LENR reactors and the grade of energy produced could meet the various end-use sectors. For reactor Types 1 and 2 with temperatures below 100° C (Grade 4) the prime market is for residential energy for refrigeration, heating appliances, water heaters, and heat pumps. The energy output (heat input) required from the source is comparatively low, but the number of units is high.

Type 1 and 2 reactors with grade 4 temperature can also meet the requirements of the commercial sector, but a major increase of output power is necessary.

For reactor Types 1 and 2 with Grade 2 temperatures (100 to 200° C), the principal energy market is for industrial boilers. As noted, boilers are a major component of the industrial sector. The amount of heat output and number of units required are moderate (middle part of the diagram).

For Type 2 and 3 reactors with Grade 2 and 3 temperatures, applications encompass a large range of energy production requirements, including high-pressure boilers and steam turbines for many uses (see also Figure 1).

Type 3 reactors with Grade 1 energy can potentially be used for the transportation sector. However, transportation with on-board energy production is a special case. Because of this need for transportability, specific energy (energy per unit of mass) comes into play. The required energy output for the transportation sector ranges from moderate to high for autos, trucks, marine craft and aircraft. The grade of energy required is high (temperatures >1000° C) for all cases.

It is noted in the study that LENR energy could contribute to transportation energy sources that are not on board, such as electric vehicle batteries, hydrogen, and synthetic fuels. However, this category is not fully analyzed.

Type 3 reactors operating with Grade 1 temperatures (above 300° C), may also be able to displace electrical power generators. Centralized generators come into the picture, either as large reactors or as assemblies of smaller units. Smaller distributed generators can be used not only for many applications, but also can be connected to the grid for input of surplus power.

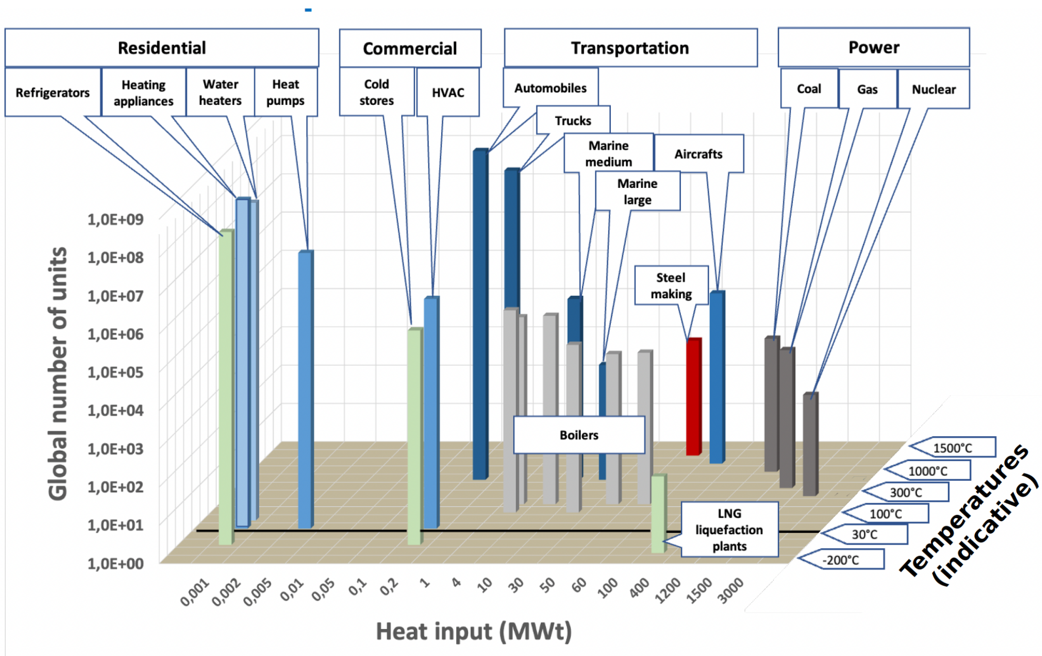

Figure 2. Present Global Uses of Heat: Tentative Representation of Heat Consumers in the World (MWt = Megawatts Thermal).

4.3. LENR Effectiveness in Displacing Fossil Fuels

The EU study may be extended by considering the relative amounts of energy produced by fossil fuels and consumed by end-use categories. The effectiveness in fossil fuel displacement is determined by the relative amount of energy produced, grade of the energy, and how quickly LENR becomes available. Displacement of these fuels is essential for dealing with the GCC crisis.

Using the US as an example, the energy picture for sources, end uses, and electrical power (which is both a producer and consumer) are shown in Figure 3 [11]. As of 2022 fossil fuels provided nearly 80% (petroleum 36%, natural gas 32%, coal 11%) of energy produced in the US. Displacement of these fuels is essential for dealing with the GCC crisis.

The effectiveness of LENR reactors in displacing fossil energy is different for different end use sectors. Several variables come into play, in particular the following.

- Development timeline and reactor availability (Type 1 and 2, then Type 3)
- Quantity of output energy required (low <0.2, medium 0.2-100, high >100 MWt)
- Grade (temperature) of energy (1 to 4. < 100°, 100-200°, 200-300°, and 300° C)
- Share of sector consumption (%, from Figure 3)
- Current fossil energy dependence (petroleum, natural gas, coal)
- Centralized vs distributed configuration
- Number of units having to be replaced (order of magnitude, 10^x)

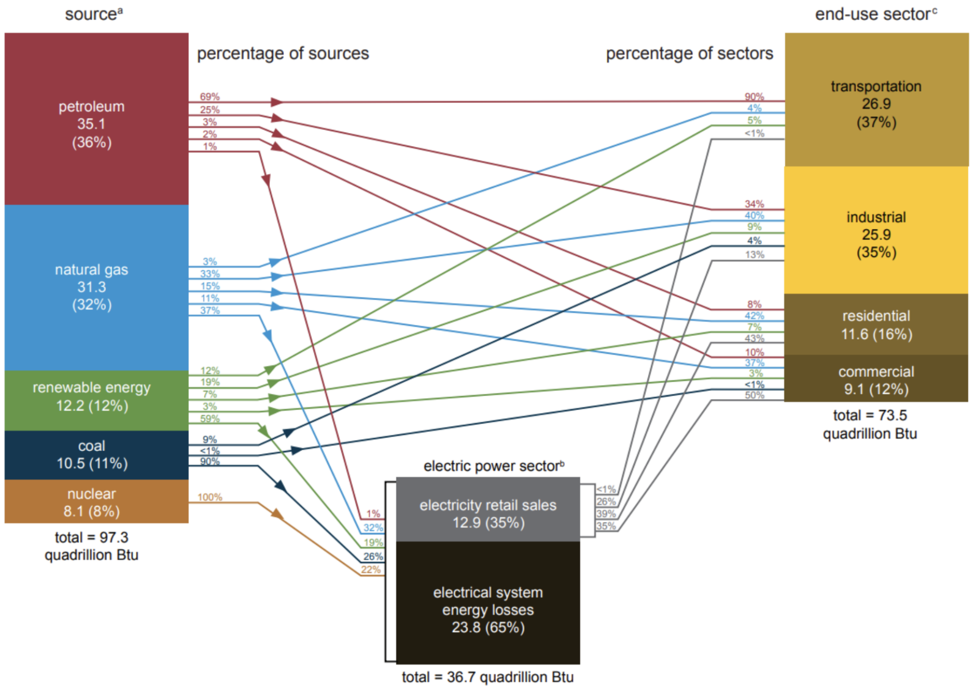

Figure 3. U.S. Energy Consumption by Source and Sector, 2021 (Quadrillion Btu).

Many additional variables that are only indirectly related to the technology, such as public acceptance and government regulation, are also likely to come into play. With the complexity of these variables and the challenge of estimating them, it is extremely difficult to develop a scenario for fossil fuel displacement. The following preliminary and simplified observations for the various sectors may make it possible eventually to prepare such a scenario.

Residential Sector. Includes refrigerators, heating appliances, water, heaters, and heat pumps (shown in the lower left corner of Figure 2).

- Availability: Early, Type 1 and 2.
- Energy output: Very low, <0.2 MWt.
- Energy grade: Very low, grade 4, <100° C.
- End use share: Low, 16%.
- Fossil dependence: High. Electricity 43%, natural gas 42%, petroleum 8%. The dependence of electrical power production on fossil fuels adds another large percentage.
- Configuration: Distributed better than centralized for local use, and to eliminate grid loss.
- Number of units required: Very high, 10^8.

Commercial Sector. Commercial use consists of primarily cold stores and HVAC (shown in the lower part of Figure 2).

- Availability: Early, Types 1 and 2.
- Energy output: Moderate. 0.2-100 MWt.

- Energy grade: Low, grade 4, <100° C.
- End use share: low, 12%.
- Fossil dependence: High. Electricity 50%, natural gas 37%, petroleum 10%. The dependence of electrical power generation on fossil fuels adds another large percentage.
- Configuration: Distributed and centralized both suitable.
- Number of units required: Moderate, 10^5.

Industrial Sector. This sector is not included in the EU study. Boilers are therefore taken as representative (located in the central part of Figure 2).

- Availability: Moderately soon to later, Types 2 and 3.
- Energy output: Moderate. 0.2-100 MWt.
- Energy grade: Moderate, grade 2 and 3, 100–300° C.
- End use share: Very high, 35%.
- Fossil dependence: Very high. Natural gas 40%, petroleum 34%, electricity 13 %, coal 4%. Electricity adds and other large percentage.
- Configuration: Both centralized and distributed suitable.
- Number of units required: Relatively low, 10^3 to 10^4.

Transportation. Includes automobiles, trucks, marine craft, and airplanes (shown in top of Figure 2). It is important to note that the following observations may be outweighed by a critical requirement of transportation, power unit (reactor) transportability, which requires a very high specific energy (energy per unit mass of reactor).

- Availability: Later, Type 3 only.
- Energy output: Moderate, 0.2-100 MWt. Very high for aircraft, >100 MWt.
- Energy grade: Very high, grade 1, >300° C.
- End use share: Very high, 37%.
- Fossil dependence: Very high. Petroleum 90%, natural gas 4%.
- Configuration: Dispersed only; centralized not suitable for transportability.
- Number of units required: Very large – cars, trucks, airplanes, 10^9.

Electrical Power. Most demanding sector (right middle of Figure 2).

- Availability: Later, Type 3 only.
- Energy output: Very high. >100 MWt.
- Energy grade: Very high, grade 1, >300° C
- End use share: Very high, 38%
- Fossil dependence: High. Petroleum, 1%, natural gas 32%, coal 25%. Renewable and nuclear, 41%.
- Configuration: 1) Distributed – located near end uses – is generally superior to centralized. Also avoids transmission loss. 2) if power plants required, centralized superior to distributed. May utilize large LENR reactors or assemblage of small reactors.
- Number of units required: Small, 10^3.

5. Public Policies for LENR Development and Deployment

Policies for support for new technologies. and for dealing with their direct and indirect impacts. are ways of government intervention to deal with market failures. Although the LENR problems of insufficient reliable reproducibility and adequate explanation have not been resolved, research to date has greatly increased the level of evidence that

LENR is a real phenomenon. As noted above, a principal factor in getting energy from LENR is the amount of R&D support and the priority (intensity) of the support for resolving theoretical, experimental, engineering, and business challenges.

Unfortunately, when LENR was rejected, public policies for its R&D followed suit and were, with few exceptions, discontinued. The need for change in these policies, based on the level of evidence of LENR has been explicitly described. The need for public policies to mitigate the secondary impacts of LENR as a disruptive technology is also addressed. [12], [13], [14]

5.1. Policies for Supporting Development

With the critical need for LENR for displacing fossil fuels, as well as dealing with their environmental impacts and the now-inevitable GCC effects, the public interest demands action. LENR's issues to-date have proven to be intractable, so the risks of adequate R&D are too high for the private sector. Government funding is therefore essential for the public interest at least in the early stages before market forces can take effect.

The evidence for the reality of LENR, and the potential for its development as a new source of energy, is strong. A recent evaluation of the level of evidence and appropriate policy response for LENR development indicates at least a preponderance of evidence (probability >50%) based only on the scientific credentials of Martin Fleishman and Stanley Pons. Confirmation of their findings by many researchers up to about 2012, bring the level to clear and convincing evidence (probability >70%). The extensive research and experimental findings in the decades since may well indicate the potential of LENR is beyond a reasonable doubt (probability >90%). The most appropriate policy response is therefore major, near-term support for LENR R&D. A crash program on the scale of the Manhattan project might be appropriate.

Given the current evidence in favor of LENR, it may be concluded that its original rejection was an error, a mistake in how science is conducted (a sociology-of-science error). The mistake has continued to worsen with the failure of science to correct the original error. These errors were greatly exacerbated by withdrawal of public support for R&D. The critical need for LENR energy, and the manifest public interest in meeting this need, mandates a reversal in current negative public policies for R&D support.

5.2. Policies for Dealing with Adverse Secondary Impacts

When LENR issues are resolved, and it is deployed to counter the effects of GCC and near-surface impacts, it will almost certainly be a disruptive technology for the energy industry. Compounding these direct effects are the anticipated indirect impacts on entities closely related to, and dependent on the energy industry. These indirect effects include, for example, coal mine and oilfield communities as well as government entities relying on taxes on energy and related facilities.

A methodology for determining social impacts of such new developments is technology assessment [15], [16]. The major steps in this method are as follows: 1) develop a multidisciplinary team of relevant experts; 2) state with clarity the market failure problems; 3) delineate the major direct and indirect impacts; 4) determine policy options for mitigating the impacts; 5) choose the most attractive options, and 6) develop and implement the mitigation plan for the chosen option. Government entities are usually the source of funding for preparing and pursuing the mitigation plans.

6. LENR Energy for Mitigating GCC Effects

It is uncertain whether LENR could have made a difference in avoiding the GCC crisis had it been developed and deployed soon after it was announced. But it is certainly true that, with the deepening of the crisis, it is now needed more than ever for meeting the energy requirements to mitigate the now inevitable impacts. LENR energy for mitigation is needed in at least three areas.

6.1. Greenhouse Gas Removal from Emissions

LENR energy is needed to reduce energy expenditures for removing GHG from emissions from burning fossil fuels for as long as it takes for the those sources to be displaced by LENR. An advantage of power plants for GHG removal is the relatively smaller number of facilities at fewer locations compared to other sectors like home and transportation units.

The technologies and associated energy requirements for carbon dioxide removal from power plants flue gas are still in development. Currently, there are three approaches to limiting carbon, none of which has yet proved to be viable. The post-combustion approach involves burning the fuel with atmospheric air and recovering the carbon dioxide from the flue gas before it is released to the atmosphere. The pre-combustion approach requires treatment of the fuel with oxygen separated from the atmosphere to produce syngas.

The syngas method utilizes hydrogen, which is the fuel, and carbon dioxide, which is separated from the syngas before the hydrogen is burned. In the oxy-combustion approach, the fuel is combined with oxygen and burned to produce electrical power. The carbon dioxide produced by oxy-fuel combustion is then removed from the flue gas similar to conventional power plants. When the viabilityand relative effectiveness of the three approaches is known, the energy required will also be understood and the potential role of LENR energy determined.

6.2. GHG Removal from the Atmosphere

Centuries of using fossil fuels as the world’s primary energy source has resulted in an unacceptably high level of carbon dioxide in the atmosphere [17]. That level must be reduced in order to reverse GCC impacts, which are already underway. Furthermore, the extent to which fossil fuels are not displaced and the removal of carbon dioxide from emissions is not a feasible, the “method of last resort” is recovery from the atmosphere.

Several approaches for extracting carbon dioxide from the atmosphere (called Direct Air Capture, DAC, or Carbon Dioxide Removal, CDR) have been proposed or tried, but none of them have yet proven to be feasible. Because the opportunities are “wide open” for using LENR in place of fossil fuel energy for removal, a few proposals are described as examples.

One company, Climeworks, has developed a system that captures carbon dioxide from the air using cellulose fiber filters [18], [19]. The captured carbon dioxide is removed from the filters with low-grade heat, and the fiber is recycled many times. If this system proves feasible, LENR energy may well have a role in meeting its energy requirements.

Another company, Carbon Engineering, passes atmospheric air over thin plastic surfaces that have potassium hydroxide solution flowing over them [20], [21]. Carbon dioxide is removed from the air by a chemical reaction with the solution to provide a carbonate salt. The salt solution is processed to form small pellets, which are in turn heated (in a calciner) to release the carbon dioxide in a pure gas form. After calcining, the pellets are rehydrated and recycled into the overall process. The higher grade of energy needed for calcining means that, while LENR energy may have a role, it may not be applicable until more advanced reactors become available.

In a third approach, Carbon Collect uses carbon dioxide sorbent tiles having a large surface area [22], [23]. The tiles are brought into contact with air and become saturated with carbon dioxide in just a few minutes. The tiles are then lowered into a chamber at the base and processed to remove the carbon dioxide and regenerate them for further use. Depending on the grade of energy needed for removing the carbon dioxide, LENR may play a role in the future.

All these approaches require energy for operation, which may present opportunities for substitution of LENR energy for fossil fuel energy. Beyond these examples, many additional approaches have been developed, several still in the conceptual stage, that may also become opportunities for LENR energy applications.

6.3. Mitigation of Large-Scale Impacts

The social and economic costs of GCC are already immense and will continue to rise. The costs of mitigating GCC impacts in order to maintain the habitability of the earth comprise a major part of these costs. The focus here is on the opportunities for LENR in dealing with selected examples of major GCC impacts. In most cases, the main LENR benefit is supplementing or replacing fossil fuels for the energy required for dealing with the impacts. Even if fossil fuels could be displaced in the near term, these impacts, because of a GCC lag effect, will necessitate dealing with the impacts for at least several decades.

Rising Sea Levels. Sea levels are rising worldwide because of two combined GCC-related changes. Increasing temperatures of the seas results in thermal expansion of oceanic water. And, warming climate is melting polar ice caps and high altitude glaciers. The combined effect causes sea level to rise resulting in incremental coastal flooding, especially during hurricane surges. Increased coastal erosion also occurs. The erosion is manifested as disappearing beaches and as additional landslides, as well as receding cliffs, which especially endangers expensive homes with scenic ocean views.

LENR energy may contribute to the large power requirements for beach restoration and landslide stabilization. The fact that 40% of the world's population resides in coastal areas (over 50% in the U.S.) renders the problem of sea level rise even more acute.

Changes in Weather Patterns. Weather changes from GCC are expressed in part as more intense storms, both hurricanes and inland thunderstorms. Cleanup from storms after floods and wind damage, including tornadoes, requires substantial energy. LENR energy may be highly beneficial for empowering the cleanup.

Modifications of Water Sources and Supplies. GCC certainly means that overall, the earth is becoming warmer, as well as drier. These changes are not uniform. – Some areas will be affected more drastically than others. In general, areas currently having inadequate water supplies will become worse, and other areas with good supplies will require water supplements. These changes are likely to require large changes in water consumption and supply patterns, which implies increases movement of water by pumping. The power for this incremental pumping may well be supplemented or provided by LENR. Its energy may also become important for powering new and existing water treatment technologies, such as treating saline aquifers or ocean water, to produce the required volumes of additional potable water supplies.

Wildfires and Air Pollution. With the increasing temperatures of the atmosphere, wildfires and their associated air pollution, will require substantial increases in energy to deal with them. LENR energy may have significant opportunities to supply the needed additional energy.

Population Redistribution. As a result of GCC-induced changes, the populations of the world's nations may be shifting substantially in the coming years and decades. Some highly populated areas may become much less hospitable, and other areas not currently valued highly may become more desirable. Weather changes, rising sea levels, water supply changes, and other issues may become severe enough for major population shifts.

Major migration of populations resulting from prolonged droughts, for example, are an unfortunate fact in human history. Immense energy will be required for building new infrastructure, movement of large numbers of people, and remediation of abandoned areas. LENR energy may well be able to help meet these energy needs.

7. LENR Energy for Dealing with Environmental Impacts of Fossil Fuels

LENR has been understood since its beginnings as a supplement to, or displacement of fossil fuels and, more recently, for its potential role in dealing with the now seemingly inevitable impacts of GCC. Perhaps not as much appreciated is LENR's promise for managing long-standing effects of fossil fuels at and near the Earth's surface. Energy from LENR may be used to reduce these environmental effects in the future for as long as fossil fuels are being used. Furthermore, LENR energy may be used for cleaning up legacy problems from centuries-long use of fossil fuels.

7.1. Energy for Unavoidable Continued Use of Fossil Fuels.

Even if fossil fuels start to be displaced by LENR energy, they will likely continue to be required for a long time. During this period, energy requirements of all phases, production, transport, storage and consumption, may be met with LENR energy. For example, it could be used to power coal mining and oil well drilling equipment. It could also be used for refinery operations, oil and gas pipelines, tank farms and pipelines for refined products, and fuel transport to the points of consumption.

A prime LENR opportunity may be for powering fossil fuel control technologies. Examples include scrubbers for sulfur dioxide removal at coal-powered plants, operations and emission control equipment in oil refineries, and management of return water from fracking for oil and gas. In summary, the objective of using LENR for future fossil fuel operations is to reduce the fossil fuel energy consumed in support of their continued energy production.

7.2. Energy for Abatement of Legacy Fossil Fuel Impacts

Centuries of fossil fuel use has resulted in many environmental issues that have long been a threat to the Earth's habitability. Laws and regulations were put in place around the world to deal with these issues long before the GCC crisis came to the fore. These legacy issues will take decades to clean up throughout the world, which in turn will continue to demand huge expenditures of energy. The potential utilization of LENR energy in dispersed configurations is particularly advantageous in meeting these requirements. Examples of LENR energy opportunities are described below.

Electrical Power Plants. The locations of coal-fired and other electrical power generation stations will require extensive remediation even when they are no longer needed and are closed. The cleanup has major power requirements both for the sites and for associated pits and ponds used for disposal of coal ash and scrubber sludge. Flue gas scrubbers have been used for decades to remove sulfur from coal combustion as a primary abatement measure for acid rain. Failure of pond embankments has resulted in releases of coal ash and scrubber sludge at a number of power plant locations. Power from LENR may be used in several configurations in power plant cleanup operations.

Petroleum Refineries. Crude oil refinery sites are generally heavily contaminated with petroleum and refined products like fuels and chemicals. Many of them have extensive subsurface accumulation of fuels that may be recovered for beneficial use. Like power plants, refineries will require extensive remediation at many locations around the world, if and when they are no longer needed. As energy from oil is displaced, power from LENR reactors may be used in different configurations for the energy required for the remediation.

Refined Product Tank Farms. One of the principal ways that energy is stored is pipelines and large "tank farms" in proximity to the locations of usage. Gas stations are typically refilled by fuel trucks that receive their loads at tank farms. History has shown that the large tanks may leak their contents into the subsurface, resulting in pollution of aquifers. Discovery and remediation of these releases are being accomplished at many locations around the world. LENR energy, particularly in a distributed configuration, maybe used for remedial activities, such as pumping for hydrocarbon recovery and removal of contaminated groundwater for treatment. The energy may also be used for treatment of the water, possibly for return to the aquifer.

Abandoned Oil and Gas Wells. Drilling for oil and gas wells is now heavily regulated to prevent leakage from wells that are dry holes or are subsequently shut down. In the decades before regulation, however, many thousands of wells were abandoned without proper closure. Many of these wells are leaking brine from deep formations into surface waters and shallow aquifers. Programs for properly plugging these wells, and remediating surface well sites, are still underway using conventional fossil fuels for energy. Inasmuch as these well plugging efforts will continue in the future, LENR energy will be utilized both before and after fossil fuels are no longer used.

Inactive Coal Mines. Coal mines that are no longer active, particularly underground mines, cause pollution both of surface waters and nearby aquifers. In many cases, the naturally occurring sulfur minerals in the coal (pyrite and marcasite) are oxidized by atmospheric oxygen, forming sulphuric acid that is carried to the surface or subsurface. Such acid mine drainage comes from within the mine and the spoil piles outside. Remediation and associated energy demands have been underway for many decades and will be required in the future. LENR energy may be used in several configurations to operate pumps and other equipment for acid mine drainage control. Energy may also be used in equipment for managing associated spoil piles.

Coal Gasification Plants. Before natural gas and then electricity became widely available for street lighting, gas derived from coal was used for this purpose. Coal gas is made by heating the feedstock coal in the absence of oxygen. This process, called retorting, also produces coal tar, which was a coproduced material used for roofing. There are hundreds of legacy retorting sites around the world with serious threats of coal tar residue to aquifers and surface waters at and around the sites. LENR energy may be utilized for cleanup of these locations, which is still in its early stages.

8. Summary

Since LENR was announced in 1989, just in time to meet the challenges of GCC, it was not able to fulfill its promise of preserving human habitability of the earth. Instead, mistakes in the sociology of science emerged to thwart the promise. Despite such problems, it remains essential to pursue LENR and realize its energy benefits not only to displace fossil fuels and their greenhouse gases, but also to provide energy to deal with unavoidable impacts as the crisis gets worse. LENR energy is also required to support the use of fossil fuels for as long as necessary and to mitigate the legacy issues of past use of fossil fuels.

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