What Is Cold Fusion and Why Should You Care?

Edmund Storms and Brian Scanlan
KivaLabs, Santa Fe NM and Greenwich, CT
e-mail: storms2@ix.netcom.com

Cold fusion or low-energy-nuclear-reaction (LENR) has now been demonstrated to initiate various nuclear reactions in solid materials without application of high energy. This creates a significant challenge for science to explain and for industry to use in a rational way. Therefore, understanding what has been discovered is very important. This paper proposes to provide this understanding.

1 Introduction

If you had read almost any major newspaper published in early April 1989, you would know about Fleischmann and Pons[1] and their amazing discovery. They even personally briefed Congress about how energy could be made in a simple electrolytic cell using only heavy-water (D_2O) and palladium. TV commentators of the time predicted cheap energy would be available into the infinite future. Laboratories around the world stopped working on other projects and attempted to replicate the claims. But then, events started to turn sour. The first and most obvious problem occurred when some famous laboratories could not replicate the claim.[2, 3] We now know the reason for most failures. A procedure is used that cannot possibly work and occasionally the heat detection devices cannot detect the amount expected even if it had occurred. One especially egregious example[4, 5] was based on data that was changed to eliminate any apparent excess. Because successful results were ignored,[6] rejection grew rapidly especially when the expected neutron and gamma emissions were not found after heroic attempts. To many people, failure of the claimed fusion to act like the known fusion process meant that the claim was wrong. Although many ideas were suggested, new explanations were not accepted. Of course, if the unexpected energy resulted from a non-nuclear source, it would be just as important, but this possibility was ignored in what seemed like a frantic effort to paint a picture of incompetence and delusion.

To advance the rejection process, the Department of Energy (DOE)[7] was asked to evaluate the claim before all the studies were finished. A panel of scientists was assembled with a chairman who was clearly biased against the idea from the start, as his book reveals.[8] Then people associated with the hot fusion program piled on. After all, if cold fusion were real, the very expensive and complex hot fusion process would no longer be justified. As a result, the difficulty in replication was used to create a myth. Even today many writers start by saying that cold fusion was rejected because it could not be replicated, which is not true.

By 1993, most efforts to replicate the claims were shut down, including many in other countries. After all, if the US DOE thought the claim was wrong, why should they get involved? Nevertheless, a few efforts continued using money mainly from private sources. The Japanese government made an effort to study the process in Japan[9] and the Toyota Company funded Fleischmann and Pons at a laboratory in France for several years. Scattered efforts continued in other countries, including in the US with help from DARPA.

The International Cold Fusion Conference (ICCF) proceedings[1] and occasionally a few open-minded scientific journals made the results public. For the next 22 years, this low-level work continued and was gradually organized in books [6, 8, 10-21] websites[22-29], and an organization devoted to the subject[27]. The evidence now clearly shows a new phenomenon of Nature. Although not yet fully understood, this phenomenon has the potential to change life as we know it. Nevertheless, this paper is not designed to prove the phenomenon is real. Many detailed publications are devoted to that effort; only a few examples of which are cited here. Instead, the general characteristics are summarized to give the reader an appreciation of what is known and of the complexity involved in arriving at an explanation. Something new and strange has been discovered for which original thinking and creative ideas are required, something most scientists search for during their careers, but seldom find. Yet, the phenomenon continues to be rejected by these same scientists. The reason for this behavior needs to be understood and changed.

2. What is Observed and What Can Be Concluded About the Process?

The phenomenon has been produced using a variety of methods and by using both deuterium and ordinary hydrogen. The initial electrolytic method pioneered by Fleischmann and Pons and now called the Fleischmann-Pons Effect has been largely replaced by a method called gas-loading or the Arata Effect. In this case, a special material containing nano-particles of palladium or nickel is exposed to high-pressure deuterium or hydrogen gas and heated. More energy is generated than is being applied to cause the initial temperature increase. In fact, on occasion the initial heating can be turned off and energy production will continue. In contrast, the electrolytic method has rarely achieved this goal. When it has happened, the behavior has been given the charming name "heat-after-death".[31, 32] A third method involves applying modest voltage to low-pressure gas, generally deuterium, which causes nuclear reactions at the cathode. In each case, success depends on a rare special condition at the cathode or in the material being used.

Before exploring these methods in detail, we need to get one major error out of the way. The phenomenon we lovingly call cold fusion is not in any way related to hot fusion. Much unjustified rejection resulted from thinking they are the same phenomenon. Efforts to change the name from cold fusion to Low-Energy-Nuclear-Reaction (LENR) or Condensed-Matter-Nuclear-Science (CMNS) have been made in an effort to move attention away from this early and incomplete description. Nevertheless, I will continue to use the old and well-known name in this paper, but with the abbreviation CF. To fully appreciate the different between hot- and cold-fusion, the contrasting differences are listed in Table 1. These differences not only strongly suggest an entirely different process is operating but that cold fusion would be a much better source of energy than hot fusion. In fact, if research for cold fusion had been given the level of support provided to hot fusion, the present delay in applying cold fusion would have been much shorter. At the present time, no one knows when hot fusion will produce commercial power [33] even though many billions of dollars have been used in the past and continue to be required for future study.

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[1] Fifteen conferences have now been held in eight different countries since 1990. Because most journals will not accept papers about this subject, the results have been published mostly in these proceedings, which are available at www.LENR.org and increasingly are published in J. Condensed Matter Nuclear Science (JCMNS).

TABLE 1

Cold fusion and hot fusion compared

COLD FUSION	HOT FUSION
Occurs only in special solids.	Occurs in plasma or when enough energy is applied.
Responds to modest energy but not required.	Requires high energy.
Uses protium (H) or deuterium (D).	Uses tritium and deuterium
Makes mostly helium (^{4}He) when D is used.[30]	Makes tritium and neutrons.
Produces insignificant radiation.	Produces significant radiation.
Can be initiated in simple devices at high O/I levels.	Requires a huge machine to produce high O/I levels.
Has been studied for 22 years using about \$0.5 B.	Has been studied for over 70 years using well over \$25 B.
Energy may be generally available in several years.	Energy may never be generally available.
Energy generators can be located in each home.	The energy generator is huge and must be located well away from populations.

What kind of evidence supports the claims for cold fusion? Hundreds of examples are available[20], but only a few can be shown here. These are based on the three different methods; electrolytic, gas loading, and gas discharge.

Electrolytic: Figure 1 summarizes 154 successful productions of heat made from 1989 to 2006. Clearly, many replications were done, some producing significant energy. All studies listed in the figure produced power far in excess of the error in the methods used. Especially impressive success, shown in Fig. 2, was reported by Energetic Inc, working in Israel[34] and using what they call superwaves superimposed on the normal DC current applied to the electrolytic cell. The difference between the two curves shows how much extra power was produced.

For this study, the palladium cathode was specially prepared by workers in Italy[35], a fabrication process that succeeds in giving a very high success rate. This experience has demonstrated once again a very important fact. As many people have shown, success depends totally on using the right materials, with success increasing as the critical nature of this material is gradually being understood and controlled. Unlike hot-fusion, the essence of the problem is not in the physics of plasma, but in the chemistry of the site where the nuclear reaction takes place. Cold fusion is especially hard to explain because it combines something unique about both physics and chemistry. First a special arrangement of atoms must form after which a unique process releases nuclear energy. Such a required marriage between physics and chemistry has made acceptance difficult for many people and the explanations more complex.

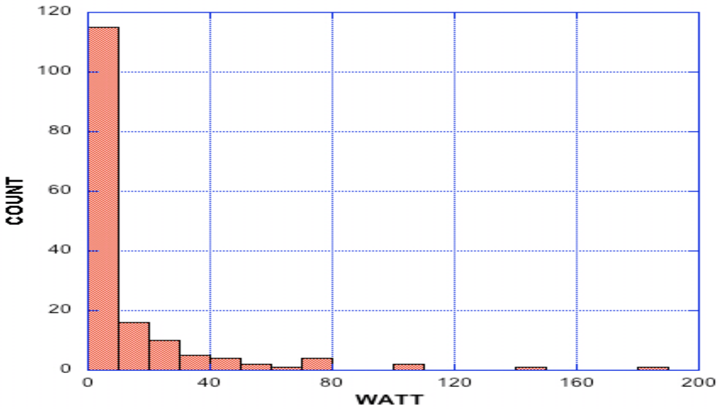

Fig. 1. Histogram of heat production in addition to that applied based on 154 independent measurements.[20]

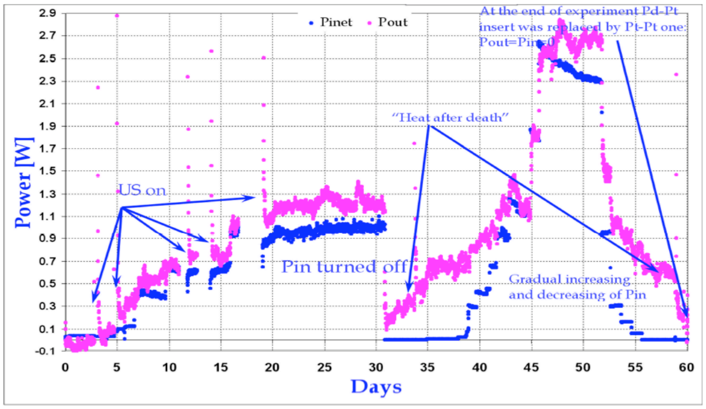

Fig. 2. Excess energy using electrolysis of D_2O + LiOD. Excess energy continued after the power was stopped (heat after death). The amount is in excess of any plausible chemical reaction. [34]

Tritium is produced on fewer occasions than helium, and with a neutron/tritium ratio less than 10^{-6}. Bockris and students at Texas A&M using electrolysis of D_2O were able to cause an especially large effect, as shown in Fig. 3. The rate of production is sensitive to applied current when it was increased at 40 hr and 80 hr. In this case, the D_2O contained significant H_2O and the palladium cathode was covered by copper dendrites, with both conditions perhaps playing a role in this unusually large production rate.

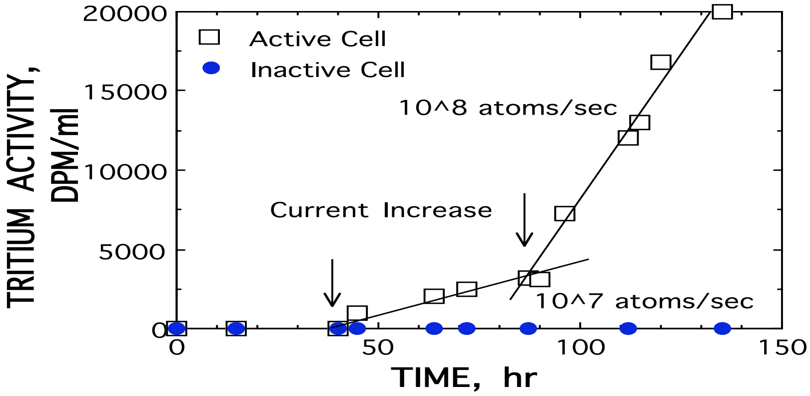

Fig. 3. Tritium production during electrolysis of D_2O + LiOD.[36]

Gas loading: Exposure of special materials to D_2 or H_2 gas also can initiate excess energy production. Arata and Zhang[37] exposed specially chosen palladium-black (nanosized palladium particles) to high pressure deuterium (D_2) at room temperature and reported the result plotted in Fig. 4. The increasing power probably resulted from an increase in D_2 pressure, while a similar cell using the same palladium, but H_2O instead of D_2O, produced no sign of energy production. Helium was also found to increase in the D_2 gas as heating continued. This method was later replicated by McKubre et. al. [38] during which heat, helium and tritium were found.

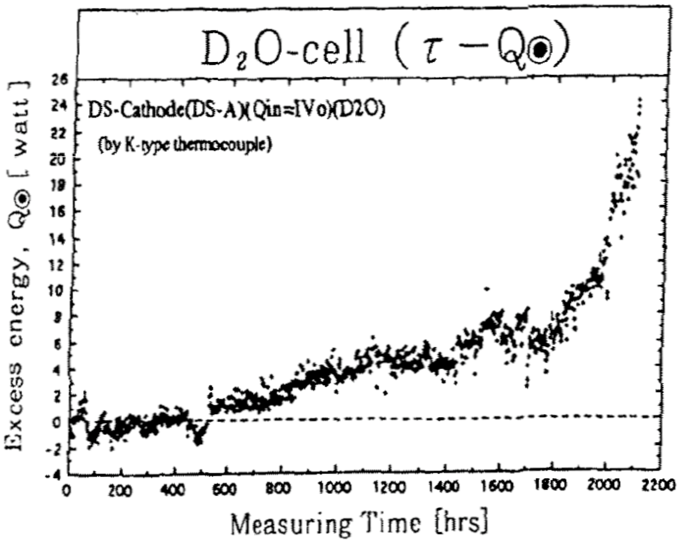

Fig. 4. Excess energy as a function of time when Pd was exposed to D_2 at room temperature.

Case[39] used a sample consisting of very small palladium particles deposited on carbon, a typical chemical catalyst, to achieve the same result as Arata and Zhang. McKubre [38] measured both energy and helium production as function of time using material supplied by Case, as shown in Fig. 5. Replication of this method has proven to be difficult because the required material is difficult to obtain. Recently, workers in Japan have used finely divided palladium, obtained by oxidizing a Pd-Zr alloy, and have reported modest heat production. [40-42]

Gas Discharge: When a voltage too low to produce hot fusion is applied to low-pressure deuterium, plasma is formed from which ions of D+ are caused to bombard the cathode surface. Depending on the nature of the cathode, various nuclear reactions of the cold-fusion type result. Claytor et al.[43] were able to produce tritium without neutrons when various alloys of palladium were used as the cathode. This method has gradually achieved significant reproducibility only when the proper alloy is used. Fig. 6 shows a typical result. The claim has been analyzed by many people at the Los Alamos National Laboratory (LANL) and concluded to be real. Although the amount of tritium is small, so is the size of the cathode during these studies. Modest improvement and increased scale could make this method an inexpensive source of tritium for various applications.

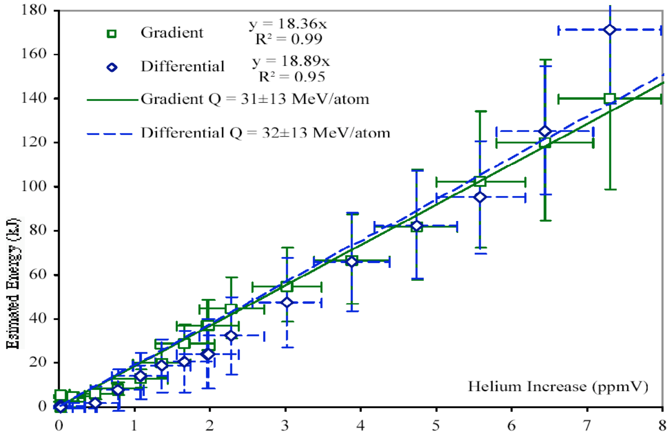

Fig. 5. Energy and helium production as a function of time using Pd on C when exposed to D_2 at temperatures up to 200°C.

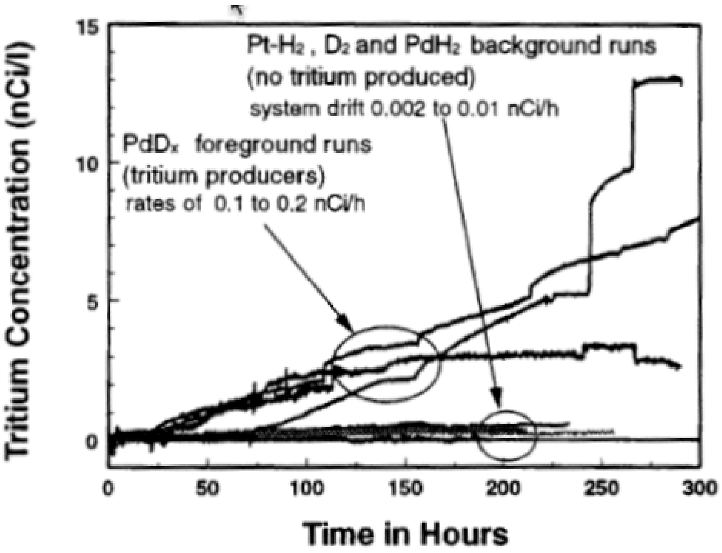

Fig. 6. Production of tritium without neutrons using gas discharge of D_2. Tritium was measured two different ways.[43]

Extensive studies in Russia[44-46] have produced a wide range of transmutation products using gas discharge. This work has also shown excess energy and unique radiation signatures, including what looks like X-ray laser emission.

Other methods have been used with growing success to initiate cold-fusion like nuclear reactions. These methods include arcing between carbon electrodes under water[47], plasma formation in D_2O[48], explosive heating of small wires[49], focused sound waves on a metal surface in D_2O[50], very high electron currents applied to a metal, and biological systems.[51] These different methods and conditions suggest two different conclusions. Either several different mechanisms are operating to cause this unique kind of nuclear reaction or a single basic mechanism is operating with the ability to function under a variety of conditions. If the latter assumption is true, these conditions severely limit the kind of the mechanism that can operate and would provide a basis to judge proposed theories.

Besides the many modest examples of unusual energy production accumulated over the last 21 years, Piantelli et al.[52-54] and now Rossi[55, 56] have succeeded in producing a very high rate of nuclear reaction using H_2 and nickel. These claims are still being examined, but have the potential to push the phenomenon into a whole new direction by improving the ease of scientific study and producing energy for commercial applications.

3. Explanation

Everyone likes an explanation before they believe what they see, with skeptics being especially demanding. In their minds, behavior must be consistent with what they expect. They are unwilling to consider a new theory or a new mechanism. When attitude is applied to cold fusion, absence of neutrons means absence of real behavior. Absence of gamma means helium is not produced. No one died from radiation poisoning, so the claimed energy was not produced.

Let's take a different path and see what Nature is telling us rather than insisting on a behavior. Of course, even people who study cold fusion do not accept all ideas. But since we have to start somewhere, the description will be confined to the basic behaviors and mechanisms the authors think are important.

The phenomenon is rarely observed and difficult to cause even when heroic efforts are made. This means that ordinary material is not the site of the nuclear process. After all, ordinary materials have been exposed to a huge range of conditions in the chemical industry without any evidence for nuclear activity been reported. Of course, some evidence might have been ignored, which is probably the case on more occasions than we know, but large effects such have been reported when cold fusion works properly could not have been ignored. In addition, the effects are frequently observed to have occurred in only certain regions of the material being used. Apparently, something rare and unusual must be created before the process can happen. We call this special condition, the nuclear-active-environment (NAE). This concept is used to focus attention away from proposed mechanisms operating in the ordinary chemical lattice, including surface properties, and encourage a focus to an unusual chemical structure. As yet, this structure has not been identified. When it is, the process will be totally reproducible and person making the discovery will be awarded fame and wealth.

You can see the contrast between how conventional science deals with this behavior and the approach taken here. Rather than using the problematic replication as a reason to reject the whole idea, the difficulty is used as an important insight about how the behavior needs to be explained. Regardless of the mechanism, it must involve a rare change in the chemical structure or conditions, both of which must be consistent with known chemical laws and behavior. In addition, these novel conditions should be visible using the conventional tools of material science, not just by detection of nuclear products. The challenge is to identify and discover how to create these required conditions.

What does the NAE do? First, it must reduce the Coulomb barrier between the hydrogen nucleus and any other nuclei in the NAE including another hydrogen. This reduction has to occur without application of more than ambient energy. Of course, extra energy from increased temperature, laser light, or RF radiation helps the process, but this is not required. The process works at detectable rates at room temperature. Because some energy is required, heat production is not detected at much lower temperatures. Nevertheless, a process that generates neutrons has been reported at low temperatures[57-59] probably resulting from hot fusion initiated by fractofuson.[60-62] Crack formation may also account for the occasional detection of low-level neutrons and energetic particles.[63-65] Regardless of the proposed source of neutrons and/or energetic particles, a distinction must be made between a mechanism producing a few events/sec based on energetic radiation and a mechanism producing over 10^{12} events/sec as required to explain most cold fusion claims, but without significant radiation.

Second, although some radiation has been detected when significant energy is made, it is never great enough to be consistent with the amount of energy. Apparently, energy is dissipated over a long enough time so that each photon and/or phonon of a large number carries only a small fraction of the total. This suggests a resonance process between the two D nuclei as they come closer together to form a helium nucleus. Such behavior is in contrast to the abrupt reaction expected and observed when two deuterons are forced together by high energy, i.e. hot fusion. Such a resonance process would require a special arrangement of atoms to initiate the process, to confine the action, and to limit the rate of energy loss. This ability is proposed to be one of the characteristics of the NAE and a behavior that makes cold fusion much different from hot fusion. Other models suggest mechanisms that release energy into a normal chemical lattice, for example through local formation of Bose-Einstein-Condensates (BEC)[66, 67], so-called "Lochons"[68], or complex wave interaction[69].

Whatever the mechanism, it would be expected to operate during formation of tritium and transmutation, but at a much smaller rate compared to helium formation. The tritium apparently does not result from fusion of two deuterons as happens during hot fusion because neutrons and other radiation are not produced. Anecdotal reports suggest tritium is more common when the heavy-water is contaminated with light-water. This experience suggests a fusion reaction between D and H, during which an electron is captured and deuterium is produced. The energy would be dissipated by the same mechanism operating when helium is produced after two D come together in the same kind of NAE. By analogy, two H could come together with an electron to produce deuterium if the H concentration were very high.

Transmutation is known to involve up to 6 D entering a heavy nucleus apparently at nearly the same time[70, 71], followed on rare occasions by fission of the resulting product.[72-74] Transmutation can only involve atoms that happened to be in the NAE because the heavy targets do not move very far in a chemical lattice. This explanation also can be used to evaluate various claims. For example, the claim by Rossi[75] that energy results from conversion of Ni to Cu by addition of an H becomes implausible. Only the few Ni atoms located in the rare NAE would be available for reaction and once these were transmuted, energy production would stop unless additional H were added to the previously transmuted nucleus, resulting in undetected radioactive elements.

Consequently, when looking for the NAE, a search should be made for a structure that would account for all observed behaviors. Obviously, the greater the amount of the structure, the greater the number of nuclear reactions would be possible, hence the greater the amount of power. At the present time, the amount of NAE is expected to be very small because it is created by random chance during advantageous treatment. The challenge is to create it in greater amount on purpose. Presumably, once a large amount of NAE can be produced in a material, the only limitation on energy production will be how fast energy can be removed.

4. How is a Cold Fusion Energy Generator Expected to Behave and be Used?

Once the NAE is created, what variables are expected to influence power production? Three major variables can be suggested.

1. Number of sites where nuclear reactions can occur, i.e. concentration of NAE.
2. Concentration of H or D in the NAE, which is related to the applied H_2 or D_2 pressure.
3. Energy available at the NAE, which is normally provided by temperature.

Each method is affected by these variables in different ways. For example, the electrolytic method suffers from relatively low temperatures while benefiting from a high effective D_2 pressure. In contrast, the gas loading method has low effective D_2 or H_2 pressure while being able to benefit from high temperatures. Both have unknown and highly variable NAE concentrations. The best way to increase the amount of energy would be to maximize all three variables.

How would we expect such a maximized system to behave? Let's assume enough NAE is present to make detectable energy at room temperature and modest H_2 pressure. Increasing the temperature at constant H_2 pressure will have two effects. The increased temperature (energy) will increase the nuclear reaction rate, hence power production. At the same time, the amount of H present in the NAE will decrease because that is how hydrogen dissolved in materials is known to behave. Consequently, the amount of power would be expected to increase to a maximum and then decrease as temperature is further increased. The temperature at which this maximum occurs will depend on applied gas pressure and on the chemical nature of the NAE. The stability of power produced by such a generator will depend on how well the temperature can be controlled and on the stability of the NAE at operating temperatures. If the NAE is gradually destroyed by the nuclear reactions, the amount of power will gradually decrease. At the present time, the stability of the NAE is not known, which creates a major uncertainty in predicting how successful this energy source will be in solving our energy problems. Presumably a dying material could be reactivated the same way it was activated initially. Commercial success depends on how often this must be done.

At the present time, cold fusion produces energy at temperatures perhaps as high as 400° C. This temperature is great enough to permit efficient conversion of the thermal energy into electric power. However, effective use of such a generator requires solution of several difficult engineering problems. For example how can the output be controlled to meet variable demand. A conflict between applications is expected such as hot air used for space heating or cooling while electric power is required for lights and charging the plug-in hybrid? A small home generator would need to respond quickly as these and other demands change. This requirement has yet to be solved.

Suppose these problems are solved and such generators start to replace conventional energy. What will be the consequences? The first industry to be affected we expect would be coal powered power plants. These generate a great deal of CO_2 and cause significant environmental damage, as they supply most of the electric energy. As people disconnect from the grid and demand for electric energy goes down, such plants will be phased out, coal mines will be closed, and many people will be put out of work. Nevertheless, I expect some of the plants will be switched to natural gas as a backup for large industrial users of electric power. Next to go will be the nuclear reactors, which are being phased out in many countries anyway. As the cold fusion energy sources become more efficient and more hybrid and electric cars are used, use of oil will decrease as an energy source. Instead, use will increase as a source of raw materials for plastic, which will become cheaper and more widely used. Many applications for this cheap energy will become possible. For example, creation of fresh water from seawater will become practical on a large scale, permitting farming in areas near the coasts where natural water is scarce. Large aqueducts will become common from the coasts to inland farms as the cost of pumping becomes trivial. Sewage water from cities will also be recycled, which will reduce demand on natural sources. Finally, energy will be available to ether protect costal cities from rising sea level by using dikes or by relocation. Of course, many other benefits can be imagined.

But like all progress, many bad effects will result as well. At first, many businesses can be expected to go bankrupt, mostly in the energy industries. Large numbers of people will lose their jobs in the resulting economic chaos. War will become more deadly as killing lasers are used on drones that have infinite range. Several oil-producing countries can be expected to experience civil war. Terrorism will become more widespread as social unrest expands before stability is finally achieved. Nevertheless, intelligent introduction of the technology might reduce these consequences. That is why knowledge about the technology and its consequences is so important at the present time, while time is still available to reduce the worst effects. In this case, ignorance is not bliss and skepticism is not a responsible response.

Now that the claim has been demonstrated to be correct, people naturally ask, “What went wrong”? Why did science make such a tragic mistake in rejecting a discovery having such important consequences to society? What is required to correct this mistake before effective response is no longer possible? That is the essential question of importance to everyone.

5. Conclusion

The phenomenon called cold fusion has been demonstrated to cause initiation of a variety of nuclear reactions, occasionally at rates able to produce commercial grade energy. The process is cheaper, easier to produce, freer of radioactive products, and likely to be more useful than the conventional source of fusion power called hot fusion.[65] Once the common myth that claims the phenomenon is false has been changed and suitable funding levels can be provided, mankind may acquire an ideal energy source, as the future requires. In the process, society needs to understand and correct the flaws that permitted such a distortion of the evaluation process used by various scientists and governments.

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