Power Generation Through LENRs: Prospects, Problems and Paths Forward

A White Paper by Steven B. Krivit

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Introduction

For the past 100 years, most scientists thought that nuclear reactions could occur only in high-energy physics experiments and in massive nuclear reactors. But experimental research, and the Widom-Larsen theory, suggest that there is more to know: Nuclear reactions can also occur in small, benchtop experiments. Low-energy nuclear reaction (LENR) research has the potential to open the door to a new kind of nuclear power generation without harmful radiation emission, greenhouse gas production, or the possibility of runaway chain reactions.

The Widom-Larsen theory, which does not require any new physics, provides a sensible, mathematically rigorous explanation for most of the previously incomprehensible experimental observations. A complete list of the Widom-Larsen papers, including critique and response to critique, are available on this Web page. A brief summary of the seven papers is available on request.

LENRs are neither fusion nor fission but instead provide a third potential pathway to nuclear energy. LENRs may also provide a means of transmuting elements, including rendering dangerous radioactive isotopes inert. LENR fuels may consist of ordinary hydrogen, along with metallic nanoparticles composed of nickel, titanium, palladium, other transition metals, or tungsten. At first glance, a clean, radiation-free nuclear energy technology sounds too good to be true; this concern has been one of the impediments to broader acceptance of LENRs. This paper outlines key evidence that establishes the scientific validity of LENRs, identifies issues interfering with its acceptance, and discusses future opportunities in LENR research.

Contents

Heat Sources

Commercial electric power produced by the burning of coal or the fissioning of uranium derives its energy from heat-producing chemical or nuclear processes, respectively. The high-quality process heat from these sources is used to boil water, which creates steam, which then turns power generation turbines, thus creating electricity. If heat from LENRs can be harnessed in a technologically and commercially viable manner, LENRs may introduce a new class of CO_2-free energy systems: one that has the high-energy density of nuclear power along with the radiological safety and convenience of fossil fuels that are chemically combusted with oxygen.

LENRs may also provide an alternative to large central-station distribution-dependent power plants. LENRs could be deployed in much smaller-sized, scalable, distributed systems providing combined heat and power for homes and businesses. If technologies with extremely high heat-to-electric conversion efficiency are developed, LENR systems could provide power for small electronics and portable devices. Being radiation-free, they would not require heavy shielding or containment.

Nuclear Evidence: Shifts in Isotopic Abundances

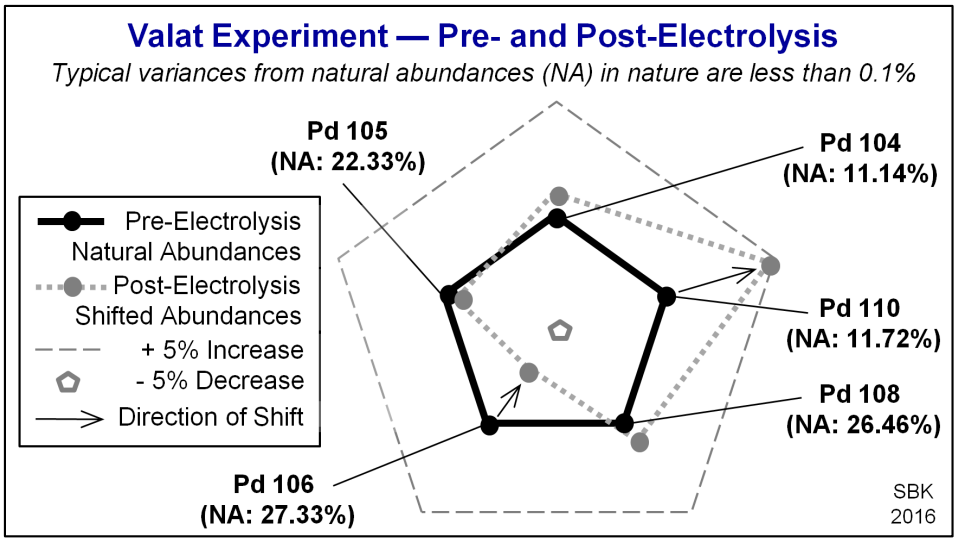
Although heat production is the primary goal, scientific credibility for LENRs has not been established by experimental heat results. Credible evidence of heat production exists in the LENR literature, but it is generally of low magnitude (milliwatts) and poor repeatability. Additionally, public confusion exists because many scientists who believe in the "cold fusion" idea regularly make the following claims:

1. Anomalous heat generation is now entirely reproducible.
2. The amount of excess energy, within batches of electrodes, is predictable and controllable.
3. LENRs have reliably produced heat 25 times greater than the electrical input.

By itself, heat production measured through calorimetry is not direct evidence of nuclear reactions. Rather, direct nuclear evidence for LENRs consists of shifts in the abundance of isotopes, transmutations from one element to a different element, small emissions of energetic charged particles and low-energy neutrons and tritium production.

Unlike heat, all of these other products are attributable *only* to nuclear processes. The bibliographies in my 2016 books *Hacking the Atom* and *Fusion Fiasco* contain extensive scientific references to such data.

One of the clearest examples of shifts in the abundance of isotopes in a LENR experiment was performed by Mathieu Valat, as part of his master's degree coursework at Portland State University in Oregon in 2011. The graph below shows shifts in the abundance of five palladium isotopes following electrolysis. Palladium-110 showed the greatest increase, 5 percent higher than the natural abundance. The solid pentagon represents the natural abundances of the palladium isotopes displayed. The distorted, dotted pentagon shows the same isotopic abundances after the LENR experiment. Such shifts in the abundance of isotopes can be explained only by a nuclear process; chemical fractionation cannot explain the magnitudes of isotopic shifts observed in these experiments. Nor can external contamination.



Shifts in the abundance of isotopes measured in an electrolytic LENR experiment

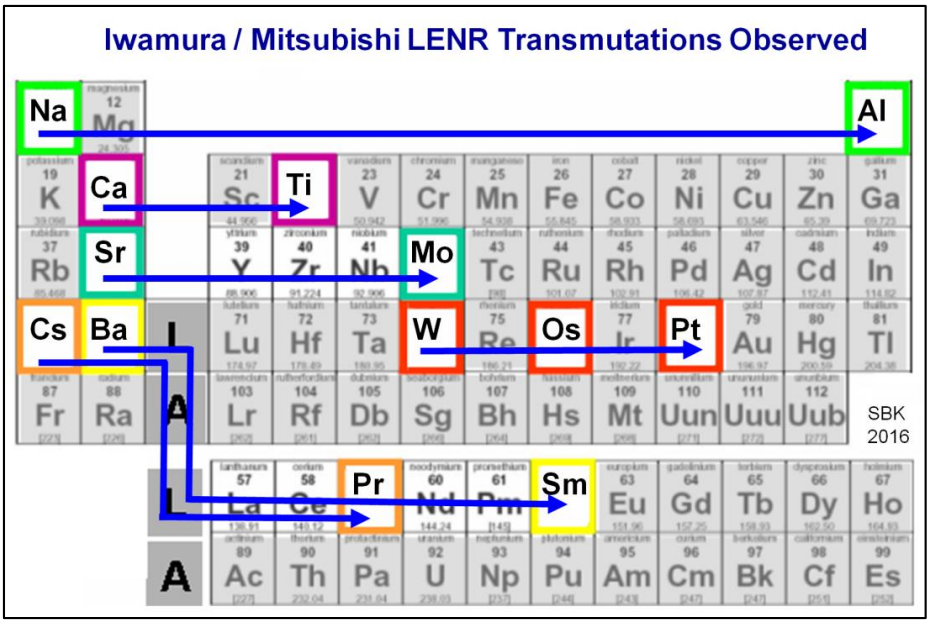
Other examples of such isotopic shifts include the 1989 observations made by researchers at the Lawrence Livermore National Laboratory and at the Naval Research Laboratory. They, too, each measured shifts in the abundance of isotopes in LENR experiments but couldn't understand or explain such results at the time.

Renowned nuclear physicist Edward Teller, learning of such results, speculated that a neutral particle (such as a neutron) caused the observed isotopic shifts.

Nuclear Evidence: LENR Transmutations

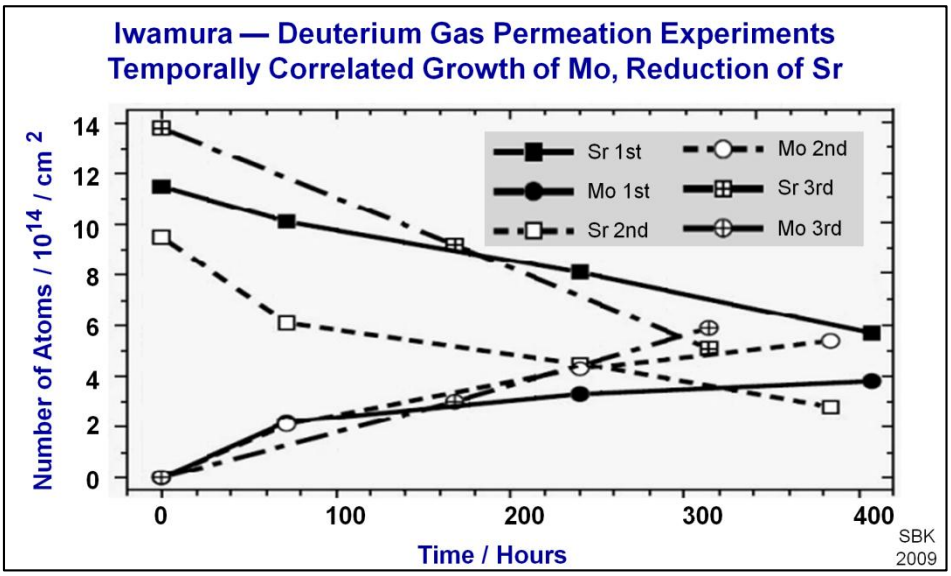
Despite the prevailing assumption in the scientific community that changing one element to another requires high-energy accelerators or large nuclear fission reactors, LENRs can cause such transmutations in benchtop experiments. The largest body of well-measured LENR transmutation results was measured and published by Yasuhiro Iwamura while he worked at Mitsubishi Heavy Industries. In a high-tech clean-room environment, for more than a decade, Iwamura and his group observed seven sets of transmutations, as mapped and summarized in the graph on the next page.

Not only did the Mitsubishi researchers observe increases in the amount of their end-product elements, but they also observed the simultaneous decrease in the amount of their starting elements. Critics — for example, David Kidwell, at the Naval Research Laboratory, and Kirk Shanahan, at the Department of Energy's Savannah River Site — attempted to dismiss the entire set of increases as well as decreases with an unlikely and unsupported speculation of praseodymium contamination, which could not possibly explain the decrease of cesium, let alone the results of the other transmutation pairs. For example, the graph below shows the increase of molybdenum and the associated decrease in strontium. Neither Kidwell nor Shanahan has published a peer-reviewed critique of the Mitsubishi experiments. Public confusion exists because scientists who believe in the "cold fusion" idea — which the Iwamura data disproves — had invited Kidwell to speak at their "cold fusion" conferences.



LENR transmutation results measured at Mitsubishi Heavy Industries

In contrast, the Iwamura group's papers were published in the peer-reviewed *Japanese Journal of Applied Physics*. Moreover, LENR researchers at Toyota Central Research and Development Laboratories published a confirmation of the Mitsubishi deuterium gas-permeation experiments in the same physics journal.

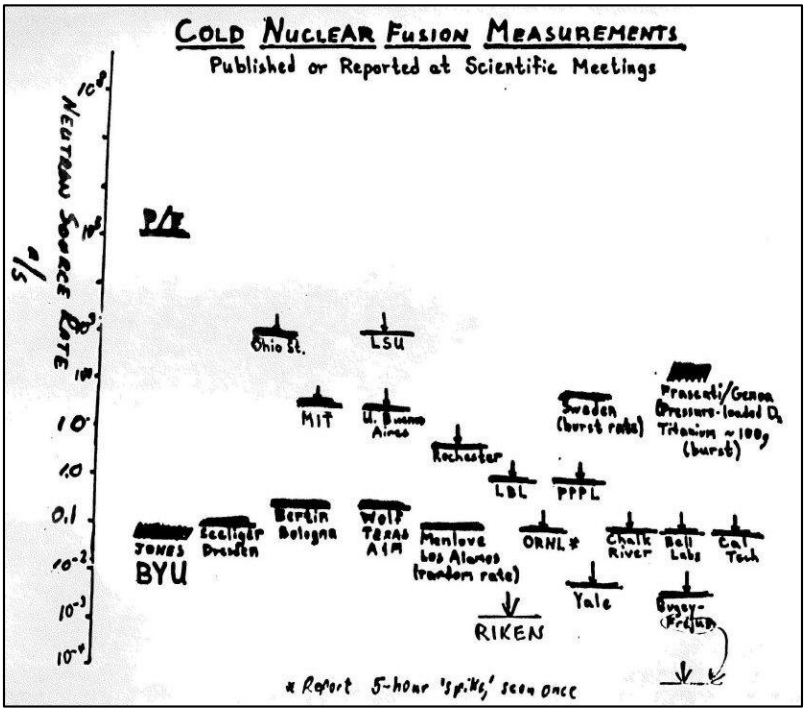


Typical increase of end-product elements and decrease of starting elements in Mitsubishi Heavy Industries experiment

Nuclear Evidence: Small Emissions of Low-Energy Neutrons

Even as early as August 1989, episodes of low-energy neutron emission, as well as sporadic bursts of low-energy neutrons from room-temperature experiments, had been successfully measured around the world. However, the observed neutron fluxes were too small and too sporadic to be the result of

nuclear fusion or fission. But if these neutrons were not being caused by thermonuclear fusion or fission processes, then by what? Nobody had any good explanations. For this reason, as with the shifts in the abundance of certain isotopes, these neutrons — direct evidence of nuclear reactions — made no sense to (and could not be explained by) scientists at that time. A hand-drawn graph, shown below, that I found in physicist Richard Garwin's archive summarizes the reported results back in 1989.



Hand-drawn graph (1989) showing reports of neutrons measured in room-temperature experiments. (Author unknown)

Garwin was a key member of the 1989 Department of Energy panel that looked at the "cold fusion" research and encouraged the DOE to disregard the new science. The y-axis is the neutron source rate in neutrons/second and is a log scale. The x-axis appears, roughly, to be time of reported observation, starting with March 1989. The values appear to be a mixture of both average (random) and burst neutron rates. News archives correlate some of the neutron reports, but some of the other labs shown on the graph never publicly reported their neutron observations from their LENR experiments.

The graph above provides only a general overview of the breadth of reports of neutron measurements in these LENR experiments. Some of the experiments listed were performed at liquid-nitrogen temperature, and some were performed at a few hundred degrees above room temperature. Countries represented are the United States, Germany, Argentina, Japan, Sweden, Canada, Italy and France. The graph indicates neutron results from MIT, the University of Rochester, Lawrence Berkeley Laboratory, Princeton Plasma Physics Laboratory, the Atomic Energy Canada laboratory at Chalk River, and Bell Labs.

In a report to the Department of Energy in the summer of 1989, researchers at Sandia National Laboratory reported "unexpected false-positive signal neutrons and neutron bursts." Argonne National Laboratory reported neutron measurements as "false-positive, up to eight times background, not reproducible." The researchers did not explain how they knew the results were false. More likely, they assumed that nuclear reactions in benchtop experiments without the expected deadly fluxes of energetic neutron and gamma radiation were simply impossible and some as-yet-unidentified artifact was responsible for the theoretically inexplicable low-energy neutron signals.

Researchers at Lawrence Berkeley National Laboratory, struggling to find a sensible explanation for their observations of neutron flux, identified them as "false-positive bursts," claiming that "mechanical and/or electrical interference" was responsible for the data. However, they had no specific explanation for the source of such interference. Researchers at Lawrence Livermore National Laboratory wrote that they "appear to have duplicated ... bursts of a few hundred neutrons." Unless their instruments coincidentally produced false signals at the time of these experiments, their observations are difficult to dismiss as false-positive. These discounted reports of neutrons in the 1989 electrolytic experiments have been deeply buried. I have made these original reports public through the *New Energy Times* Richard Garwin "Cold Fusion" Archive.

Experiments performed at India's largest nuclear research facility, the Bhabha Atomic Research Centre (BARC), provide detailed technical evidence not only for neutron bursts but also for production of tritium, roughly correlated in time, with the neutron emissions. Those results were published in the 153-page book *BARC Studies in Cold Fusion*, published by the government of India. I have, with its permission, made an electronic reprint of the book publicly available.

Summary of Results From Groups Reporting Tritium and Neutrons in BARC Electrolysis Experiments							
Serial # (Date(s))	**Cathode**	**Shape**	**Area Cm^2**	**Anode**	**Neutron Yield**	**Tritium Yield**	**n/T Ratio**
1 (May 21/1989)	Ti	Rod	104	SS pipe	$3x10^{7}$	$1.4x10^{14}$	$2x10^{-7}$
2 (April 21/1989)	Pd-Ag	Tubes	300	Ni pipe	$4x10^{7}$	$8x10^{15}$	$5x10^{-7}$
3 (June 12-16/1989)	Pd-Ag	Tubes	300	Ni pipe	$0.9x10^{7}$	$1.9x10^{15}$	$5x10^{-7}$
4 (May 5/1989)	Pd-Ag	Disks	78	Porous Ni	$5x10^{6}$	$4x10^{15}$	$1.2x10^{-9}$
6 (April 21/1989)	Pd	Cyl.	5.9	Pt Mesh	$3x10^{6}$	$7.2x10^{13}$	$4x10^{-8}$
7 (June-Aug/1989)	Pd	Cube	6.0	Pt Mesh	$1.4x10^{6}$	$6.7x10^{11}$	$1.7x10^{-6}$
8 (Jan-Apr/1990)	Pd	Pellet	5.7	Pt Mesh	$3x10^{6}$	$4x10^{12}$	$1x10^{-5}$
9 (July/1989)	Pd	Ring	18	Pt Mesh	$1.8x10^{8}$	$1.8x10^{11}$	$1x10^{-2}$
							SBK 2016

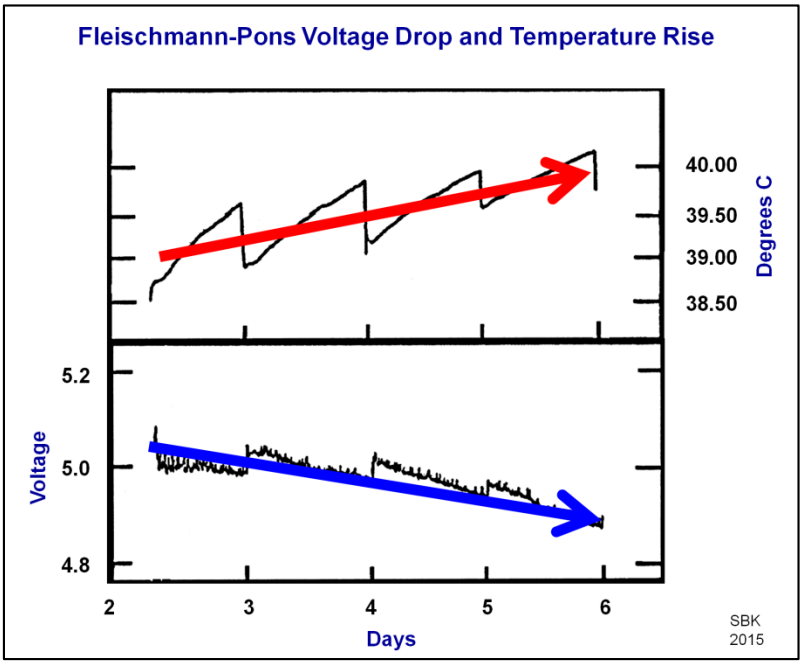
List of experiments performed at BARC showing bursts of low-energy neutrons and time-correlated production of tritium.

Most researchers active in the field in 1989 gave up in frustration after the first year, if not the first month. The experiments were difficult to repeat successfully, the results appeared to make no theoretical sense, and funding became increasingly scarce.

LENR Power: Good Science

The good news about LENR as a possible future energy source is that an abundance of evidence shows, qualitatively, that some sort of new type of heating process is occurring in these experiments. Here are some examples of these indicators.

Imagine seeing a pot of hot water on the stove, turning the power setting down and, instead, seeing the water get hotter. In 1991, Fleischmann published the graph below. (I have added the large arrows for clarity.) With input current held constant, the temperature of the electrolytic bath increased at the same time as the voltage decreased. In ordinary electrolysis, as with heating water on the stove, the temperature of a water-based electrolyte should decrease commensurately with the decrease in input power. In this case, the opposite effect occurred, indicating the presence of an unexplained heating process.

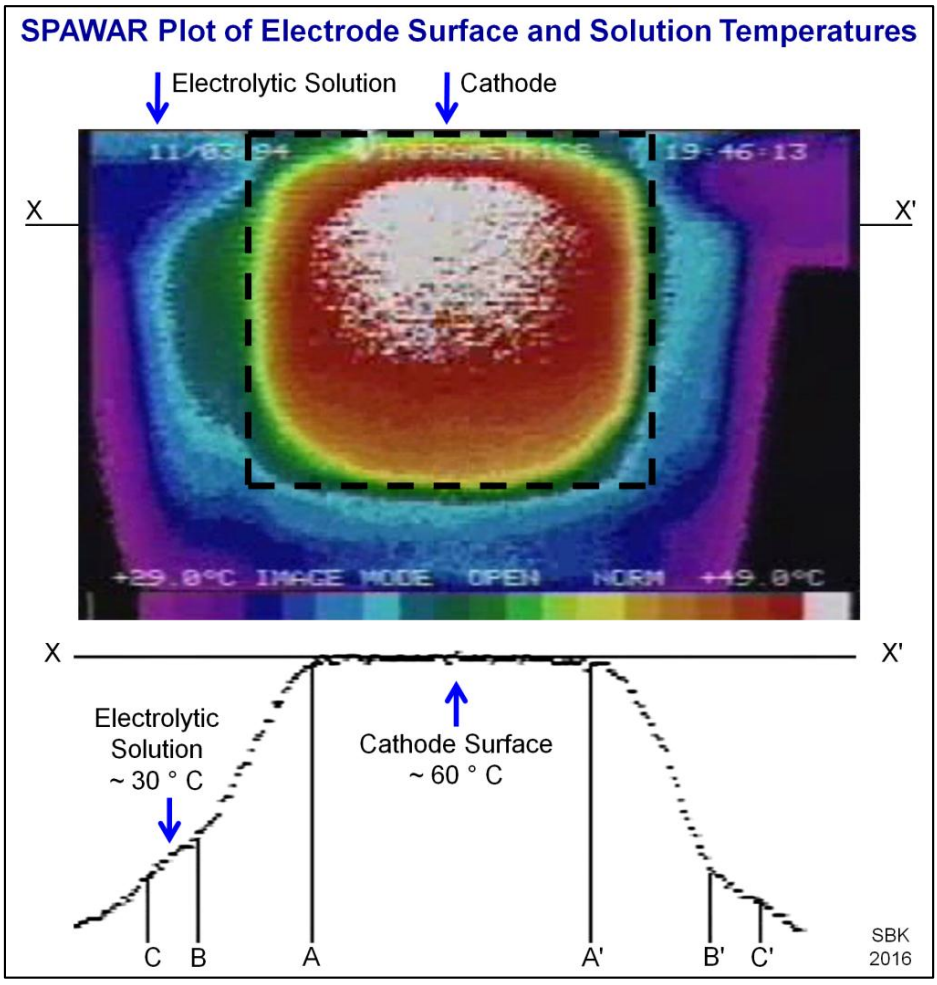


Fleischmann-Pons data showing heating anomaly

Another qualitative example of the heating effect is the set of infrared (IR) video recordings made in 1994 by the U.S. Navy's Space and Naval Warfare Systems Center (SPAWAR) LENR group in San Diego. The measurements were conducted with the help of Massoud Simnad, a professor at the University of California San Diego, and Todd Evans, a researcher at General Atomics Inc. who provided the IR video camera.

An unexpected increase of temperature occurring simultaneously with decrease of input power was also observed by the Francesco Piantelli group in Italy, using a nickel-hydrogen gas system. Moreover,

several instances were reported in which relatively high rates of heat were produced from tiny cathodes for prolonged periods after all input power was turned off. Chapter 36 in *Hacking the Atom* discusses such unexpected and unusual thermal events.

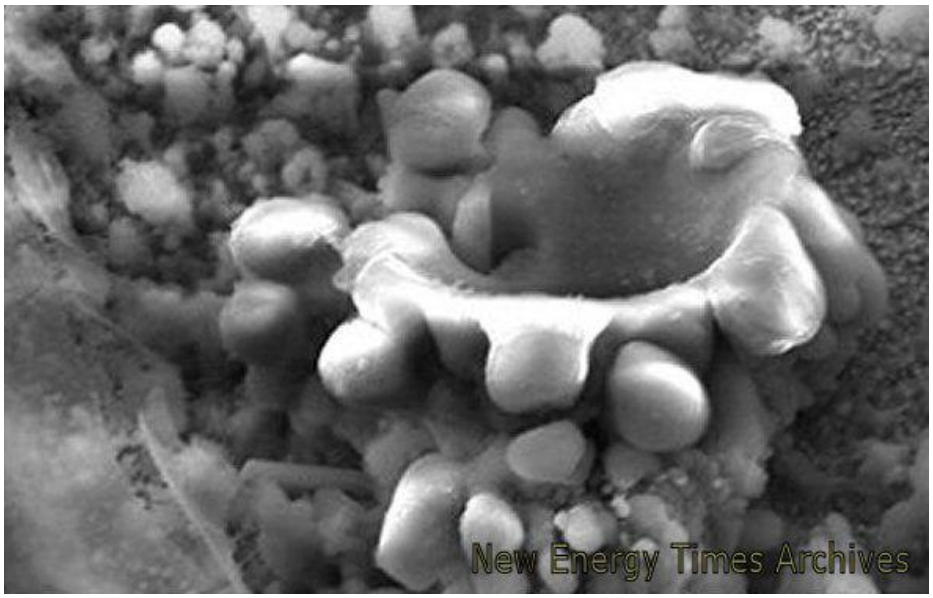


SPAWAR group's infrared image and plot showing heating anomaly

The SPAWAR image above shows that temperatures are highly elevated in microscopic hot spots that occur on an electrolytic cathode's surface. Post-experiment scanning electron-microscope (SEM) images of such surfaces have shown the effects of very rapid local melting. In some cases, boiling of metals at hot spots is apparent, indicating temperatures of 4,000-5,000 C, at distinctive microscopic sites that structurally resemble blow-out craters. Using secondary ion mass spectroscopy (SIMS), researchers have detected nuclear transmutation products at or near these sites, which support the nuclear character of heat production on cathode surfaces. These high-temperature events were produced in LENR cells using just a few Watts of input power.

Quantitative analyses have shown careful, calorimetrically measured excess heat in the field. However, calorimetry is a complicated measurement and analysis process that can raise technical issues and give rise to arguments among experts that are difficult for non-experts to follow. On the other hand, the qualitative, concrete examples of anomalous heating, as shown above, make moot

the question of whether an excess-heat effect exists. The U.S. Navy SPAWAR LENR group members had published 30 peer-reviewed journal articles before their retirement and the discontinuation of LENR research at SPAWAR.



SPAWAR image of LENR cathode showing melted palladium and possible evidence of flash boiling (Note apparent frozen droplets of metal on perimeter of crater.)

LENR Power: Poorly Reproducible

Some LENR researchers and their colleagues had claimed that electrochemical LENR systems can produce 25 times more heating power than the input electrical power. This happened only once, according to published documents. In November 2004, Arik El-Boher, a researcher with now-defunct Energetics Technologies Co., in Omer, Israel, reported an electrochemical experiment, No. 64a, that produced a calorimetrically measured excess-heat gain equivalent to 25 times the electrical input power to the cell. The Energetics group was never able to repeat the result of that experiment. In that same series of experiments, the next best experiment, No. 64b, showed a peak heat gain of 15 times, and another experiment, No. 56, showed a peak gain of 8 times.

More typical are the modest results, published in the American Chemical Society Low-Energy Nuclear Reactions Sourcebook, as reported by a consortium of scientists including those from Energetics Technologies, SRI International and ENEA, the Italian National Agency for New Technologies, Energy and the Environment, in Frascati, Italy. The consortium reported its best efforts to replicate the Energetics Technologies No. 64a experiment. Researcher Vittorio Violante, at ENEA — claimed by his SRI International colleague Michael McKubre to be the only scientist in the world who knew how to reliably produce good working cathodes — could not reproduce the Energetics Technologies No. 64a excess-heat result.

Replication attempts were performed at SRI between 2006 and 2007. A set of 23 experiments measured excess heat that equated to an average peak of 1.38 times the electrical input power. The typical amount of macroscopic, calorimetrically measured excess heat, as has been the case nearly

throughout the history of the field, was only in the milliwatt range. Four of the 23 experiments showed a peak excess heat greater than 1 Watt: 1.800, 2.066, 1.250 and 2.095 Watts. By the time McKubre resigned from SRI International in 2016, he was still unable to produce further-improved excess-heat results. Nevertheless, these data do support the assertion that heat production occurs in LENRs. The data also show that, when batches of cathodes have performed well, significant magnitudes of heat production has only occurred rarely.

The best result in nickel-hydrogen-gas LENR experiments was reported in 1998 by Piantelli and his colleagues and published in the peer-reviewed journal of the Italian Physical Society, *Il Nuovo Cimento*. In that experiment, researchers measured peak excess heat of 38.9 Watts, with electrical input power of 101.5 Watts. That experiment produced excess heat continuously for 278 days. At its peak, the experiment produced 1.3 times as much heating power as the electrical input power that it used.

The problem, as theorist Lewis Larsen, co-author of the Widom-Larsen theory explains, is that the solution to reliable production of heat depends on: a) correct theoretical understanding of the mechanism, b) proper parameters and engineering at the nanoscale level, and c) understanding of surface physics, among other requirements. Larsen likens the efforts thus far by electrochemists, materials scientists, and metallurgists, who have attempted to produce LENR heat without precision nanotechnology, to the use of hand tools. In fact, some researchers have used hammers and hand-cranked cold rollers to fabricate their electrodes.

LENR Power: Bad News

In 2011, a number of well-known researchers in the LENR field began promoting heat claims made by an Italian man, Andrea Rossi, that had no credible scientific support. The scientists included Michael Melich, Edmund Storms, Michael McKubre, David Nagel, Mitchell Swartz, and Mahadeva Srinivasan, all of whom had been researching or managing LENR research since 1989. Physics Nobel laureate Brian Josephson joined the Rossi promotion, as well.

Rossi was convicted of fraud in a previous business venture, ran two other energy schemes, caused environmental damage in northern Italy, contaminated the ground with dioxin, and served time in Italian prisons twice. More than 100 news stories in a variety of Italian newspapers, over a decade, confirm Rossi's Italian financial and environmental criminal history.

After finishing his first energy scam in Italy, Rossi secured a contract from the U.S. Army based on his claim that he could produce thermoelectric devices that would yield unprecedented heat-to-electricity conversion efficiency. Rossi told the Army he would make devices that could produce 800-1,000 Watts each, but Rossi's devices produced only 1 Watt of direct-current electricity.

In 2011, Rossi claimed to have developed working versions of 1 Megawatt (thermal) industrial LENR power plants, yet his system's thermal performance was never truly independently verified. Despite Rossi's assertions, there was never any verified sale of any such power plant. All evidence indicated that his power plant claims were just another fraud. In July 2011, I met Rossi, interviewed him, observed and videotaped his device and, on returning to the U.S., consulted with dozens of engineers

and technical experts. I concluded that his claims were fraudulent, and I published the reasons for my conclusion.

Despite Rossi's track record and my published investigation, from October 2012 to June 2013, Industrial Heat, a North Carolina-based company, paid Rossi $11.5 million for his claimed technology. Ignoring Rossi's history and public criminal record, Industrial Heat trusted and allowed Rossi to perform the initial due diligence system test on its behalf.

In the next phase of the agreement, Industrial Heat attempted its own independent system test without Rossi's presence. It didn't work. Had it worked as claimed, Industrial Heat was contractually obligated to pay Rossi another $89 million. On April 6, 2016, after that year-long test, Rossi preemptively sued Industrial Heat in the U.S. District Court for the Southern District of Florida for non-payment of the $89 million. On Aug. 6, 2016, Industrial Heat counter-sued, accusing him of fraud. On Nov. 16, Judge Cecilia M. Altonaga denied Rossi's motion to dismiss the counter-lawsuit. Her description of Rossi's actions included "complete fabrications … using fatally flawed methodologies," confirming what I had reported in 2011.

David Nagel, a retired Naval Research Laboratory manager, was one of Rossi's most eager promoters. In May 2011, Nagel gave a presentation at the 15th International Conference on Emerging Nuclear Energy Systems, in San Francisco, California. According to his slides, he said that Rossi's apparatus had heated an Italian factory in 2007 for 24 hours per day for six months and, as a result, had reduced the factory's electricity bill by 90 percent.

Edmund Storms, a retired radiochemist from the Los Alamos National Laboratory, one of the most knowledgeable experts in LENRs — and the most prolific "cold fusion" advocate — promoted Rossi.

"The entire field of cold fusion will grow rapidly and provide jobs for those of us who have slaved in the dark for so long. Personally, I hope [Rossi's apparatus] works as claimed, and I will do everything I can to promote the idea and work to make it better. Kicking Rossi at this stage just because the claim is not fully proven seems counter-productive to everyone. We desperately need the Rossi claim to be real," Storms wrote.

Meanwhile, in Rossi's nearly empty garage in Bologna, Italy, which he called a laboratory, Rossi and his collaborators always seemed to be wearing heavy coats while working on his nickel-hydrogen gas system. Nagel also said that Rossi had 97 systems operating in four countries. However, credible evidence of a single such system, or any independent evidence of Rossi's extraordinary excess-heat claims, never materialized.

Nevertheless, Nagel told *Chemical & Engineering News* in October 2016 that he doesn't think that Rossi is a fraud. In fact, Nagel told *C&EN* that Rossi's nickel-hydrogen gas system produces excess heat at a rate of 400 times greater than the input electrical power. Promotion of Rossi and his claims by qualified scientists with broad knowledge of LENRs, like Nagel, Storms, and McKubre, caused significant damage to the reputation of the field.

The State of the Art

The current state of legitimate research is difficult to determine. In the U.S., a few individuals and small companies claim to be close to delivering commercial LENR technology. Similar "near-commercial" claims been made for three decades. In my opinion, no company is close to delivering a commercially usable LENR thermal source.

A number of large, well-established organizations in the U.S. likely are performing LENR research, but they are being careful to stay out of the spotlight. For example, Boeing and NASA have publicly revealed some of their research and development work and patenting activity on the subject. Visitors from a variety of international institutions and industrial companies, as shown by their IP addresses, have visited the *New Energy Times* Web site for many years.

Three years ago, Atomic Energy Canada Ltd. (AECL) produced a 150-page internal report that surveyed the subject, based on publicly available information. Royal Dutch Shell spoke with some LENR researchers a few years ago to learn about the research. LENR research is being sponsored by the National Natural Science Foundation of China and the Japanese government through its New Energy and Industrial Technology Development Organization.

Within days of my reporting in 2015 about the Japanese issuing a request for proposals for LENR research, the government removed the request-for-proposal file from its Web site. This is one sign among other indicators that technology companies and organizations are seriously interested in LENRs but that they do not want such activities in the public spotlight. The reasons for this reluctance likely are based on competitive interests as well as the field's remaining stigma.

Three Impediments: Human Issues

Edward Teller, after witnessing just the first six months of the conflict, remarked, "I do not remember any case in my lifetime in science when so many experts have differed for such a long time on such relatively simple and inexpensive experiments."

The state of LENR science cannot be understood without examining the human issues and three non-technical impediments.

Impediment #1

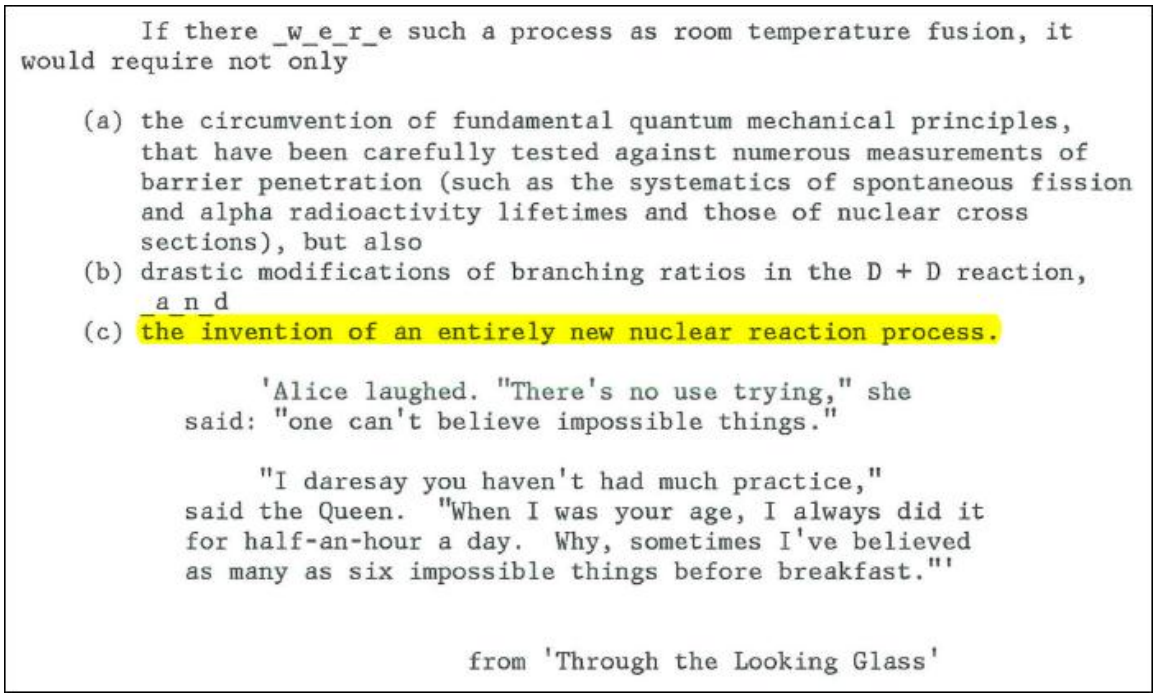
The first impediment is the lingering social stigma from the 1989 announcement by Martin Fleischmann and Stanley Pons of room-temperature "fusion" and the ensuing fiasco. Fleischmann and Pons and "cold fusion" are regularly used as metaphors for "bad science."

Impediment #2

The second impediment is that nuclear reactions initiated by low-energy stimuli, devoid of deadly radiation, have been difficult for many scientists to accept within the framework of their understanding of science.

Despite the substantial body of experimental data and the Widom-Larsen theory, which suggests a mechanism to suppress gamma radiation, the proposition that a new type of radiation-free nuclear process exists is heretical. This is evident in documents written by scientists selected by the U.S. Department of Energy (DOE) in 1989, whose job it was to objectively evaluate the evidence for "cold fusion" on behalf of the nation. Most telling are the statements in a draft of the "fusion products" section of the DOE "cold fusion" panel report, as reported in my 2016 book *Fusion Fiasco*.

Physicists Robert Schiffer and Richard Garwin were on the team tasked with evaluating the experimental evidence for nuclear products. Instead, they said that they could not believe the confirmatory nuclear evidence given to them by U.S. and Indian laboratories. As a result, they simply removed the data. Schiffer wrote the draft of the section and sent it to Garwin for review. Here are two excerpts:



If there _w_e_r_e such a process as room temperature fusion, it would require not only

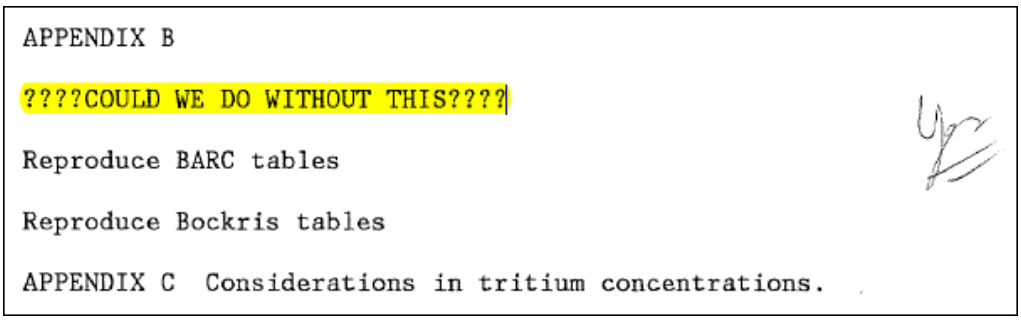
(a) the circumvention of fundamental quantum mechanical principles, that have been carefully tested against numerous measurements of barrier penetration (such as the systematics of spontaneous fission and alpha radioactivity lifetimes and those of nuclear cross sections), but also
(b) drastic modifications of branching ratios in the D + D reaction, _a_n_d
(c) the invention of an entirely new nuclear reaction process.

'Alice laughed. "There's no use trying," she said: "one can't believe impossible things."

"I daresay you haven't had much practice," said the Queen. "When I was your age, I always did it for half-an-hour a day. Why, sometimes I've believed as many as six impossible things before breakfast."'

from 'Through the Looking Glass'

In fact, an entirely new nuclear process that involves neither fusion nor fission *has* now been tentatively explained by Larsen and Widom.



APPENDIX B

????COULD WE DO WITHOUT THIS????

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APPENDIX C Considerations in tritium concentrations.

Excerpts from Oct. 4, 1989, draft of fusion-products section of "cold fusion" assessment report submitted to the Department of Energy (PDF)

Garwin's handwritten "yes" confirmed to Schiffer his agreement to remove experimental evidence of tritium and neutrons that conflicted with the limit of their theoretical understanding of nuclear science. On Page 6 of this paper, I have reproduced one of the BARC tables — of tritium and neutron emissions — that Schiffer and Garwin elected not to show to the Department of Energy and the American public.

Garwin is a brilliant scientist world-renowned for his design of the first thermonuclear fusion bomb. He and I have communicated about LENRs extensively, even once at his kitchen table. I have discussed the Widom-Larsen theory and many experimental results with him. As my books *Fusion Fiasco* and *Hacking the Atom* show, his denial of LENRs was based on random guesses, without direct evidence, about errors that might have occurred in LENR experiments.

In 2011, Joseph Zawodny and I published a brief technical explanation of the Widom-Larsen theory in the Wiley & Sons *Nuclear Energy Encyclopedia*. We focused on the role of surface plasmon polaritons and collective effects that, according to the theory, produce ultra-low-momentum neutrons. In 2013, I published a more in-depth explanation of this theory in an Elsevier reference collection. It's an extremely complicated theory, and these are good starting places. My book *Hacking the Atom* provides a complete explanation of the theory for lay readers. This Web page provides links to all the Widom-Larsen papers and more.

In my discussions with Garwin, he was unable to identify any flaw in the theory. However, neither experimental data nor this promising theory has convinced Garwin to publicly admit that he may have been too hasty in 1989 in his bet against the new science. On my way out of his kitchen, though, he suggested that cracks might have emerged in his disbelief.

“If it were true, it would be really very interesting. And when something that you don’t believe turns out to be true, well, you never know what the consequences would be,” Garwin said.

Edward Teller, Garwin's colleague, was more forward-thinking, as he wrote in October 1989: "Perhaps a neutral particle of small mass and marginal stability is catalyzing the reaction. You will have not modified any strong nuclear reactions, but you may have opened up an interesting new field."

German theoretical physicist Max Planck (1858-1947) explained that "a new scientific truth does not triumph by convincing its opponents and making them see the light, but rather because its opponents eventually die, and a new generation grows up that is familiar with it." Planck's insight, informally expressed as "science advances one funeral at a time," seems applicable here.

One exception was Robert Park, the former director of the American Physical Society. He was well-known for his caustic and hostile comments about topics he considered to be pseudoscience.

For example, on May 5, 1989, he wrote, "The corpse of cold fusion will probably continue to twitch for awhile, even after two nights of unrelenting assaults at the APS Baltimore Meeting."

Seventeen years later, the corpse was still twitching. In 2006, he conceded, “Low-energy nuclear reactions are real phenomena, though poorly understood. There’s probably something there, but it’s not well-understood yet.”

Impediment #3
The third impediment is the insistence by the remaining followers of Fleischmann and Pons that LENRs are explained by nuclear fusion. At the American Chemical Society national meeting in 2008, I identified eight major categories of inconsistencies between deuterium-deuterium fusion and LENRs. These are listed in Chapter 29 of *Hacking the Atom*.

Paths Forward

The key to developing the LENR thermal phenomenon from a science curiosity to a commercial technology lies in the proper use of nanotechnology, with a systematic program to elucidate and explore the basic science underlying LENR. Devices must be fabricated with defined nanoscale-level structures so that the tiny LENR hot spots, which now randomly produce temperatures in the thousands of degrees, can be precisely duplicated, engineered, manufactured, and controlled.

Based on Larsen's calculations, a square meter of a planar LENR device could theoretically produce a 4.28 MW thermal power source. This is an immense amount of power, 4,000 times the amount of power generated by an ideal solar panel of the same size. (*Hacking the Atom*, Chapter 36)

Observers of LENR research, who understand its foundation of credible scientific research, often wonder what will be required to attract the interest and resources necessary to solve the scientific and technological problems. Some observers have said that only a macroscopic repeatable demonstration of a heat-producing device will overcome the non-technical impediments. This will almost certainly never happen. Nobody who develops such a device will be giving any public demonstrations. Instead, such people will secure large strategic partners and do their best to quietly get the first revolutionary products out into the global marketplace.

Larsen disagrees that such a public demonstration device is necessary to inspire and encourage widespread research and development. He points out that certain experimental methods can consistently show evidence of nuclear reactions, and new researchers may be able to see results for themselves:

> Mitsubishi's thin-film palladium-oxide heterostructure gas-permeation experiment is very reproducible with respect to creating transmutation products. Similarly, a properly designed exploding-wire or carbon-arc experiment will produce microscopic quantities of spectroscopically detectable transmutation products every single time. Every transmutation product is accompanied by production of heat. However, there are relatively small numbers of microscopic LENR-active sites in such experiments today, and therefore dramatic, measurable macroscopic amounts (Watts) of excess heat will not be observed.

> If the Widom-Larsen theory and proper nanotech fabrication techniques are utilized, thin-film and dusty plasma devices can be designed that contain vastly larger numbers of active LENR sites and will consequently produce substantial amounts of macroscopic excess heat. Once reproducible fabrication of large numbers of LENR-active sites per unit of volume or area is successfully achieved, commercialization for power generation is then mostly a matter of scale-up and integration of LENR thermal sources with various types of off-the-shelf energy conversion subsystems, including thermophotovoltaic devices that directly convert heat to electricity.

According to Iwamura, the transmutation results from his LENR gas-permeation experiments were closely but not identically replicated by Toyota. Osaka University and Iwate University reported similar replications.

The apparatus for the Mitsubishi experiments cost several million dollars. Other types of experiments are much less expensive. These include exploding-wire experiments (Chapters 18 and 19 in *Fusion Fiasco*, Chapter 22 in *Hacking the Atom*) and the Proton-21-type experiments. See my "Review of Low-Energy Nuclear Reactions," published by Elsevier in 2013.) References for carbon-arc experiments, performed in the U.S., India, and China, are in Chapter 3 of *Hacking the Atom*. Although transmutation results in these other experimental designs are not as unequivocal as those in the expensive Mitsubishi experiments, any findings of shifts in the abundance of isotopes or transmutation of one chemical element to another would be very difficult to dismiss.

Two paths are likely:

1. A well-funded research and development program sponsored by a large, established for-profit corporation that has a crucial strategic interest in development and direct use of LENR technology. Examples include multinational oil and gas companies to use LENRs as CO_2-free process heat, battery manufacturers to use portable battery-like LENR power sources that would vastly outperform chemical batteries, and aerospace manufacturers to use LENRs for high-performance onboard power sources in manned or unmanned aircraft or spacecraft.
2. Sponsored programs having the aim of broad education and advancing basic science rather than commercial research and development. Examples of potential sponsors include private philanthropists, a federal agency like the National Science Foundation, or a nonprofit corporation like the Electric Power Research Institute.

On Feb. 14, 2017, the *New York Times* reported that "India's rapidly worsening air pollution is causing about 1.1 million people to die prematurely each year and is now surpassing China's as the deadliest in the world."

LENRs represent an opportunity for a potential new energy technology based on virtually unlimited supplies of fuel materials: hydrogen along with lithium, carbon, and various metallic elements. Moreover, LENRs represent an opportunity to develop a revolutionary new source of sustainable, carbon-free energy in a world heavily dependent on the burning of non-renewable fossil fuels.