Reflections on ICCF23:

Lattice Confinement Fusion and Electron Screening

Lawrence Forsley*

The following flows from a series of phone conversations in late July 2021 following the virtual ICCF23 Conference hosted in Xiamen, China in June 2021.

Infinite Energy (IE): What did you think of ICCF23?
Lawrence Forsley (LF): I was pleased they held it at all, considering the worldwide COVID-19 lockdowns. The virtual format worked better than I expected, save for the 15 hour time difference between China and Ocean Beach, California, where I am. Dr. Zhong-Qun Tian, a professor at Xiamen University in China, chaired the conference. I understand that he previously arranged the satellite conference during ICCF20 held in Sendai, Japan in 2016. His staff were great; the session co-chairs did a good job of keeping talks on time.

IE: You were an invited Plenary Speaker, presenting on June 10. Can you tell us a bit about the talk?
LF: I contrasted LENR and hot fusion in my talk, "Conventional Fusion in an Unconventional Place," that I prepared with Dr. Pamela Mosier-Boss. Since I couldn't count on Internet stability, I made a narrated PowerPoint with an .mp4 movie I sent to the conference in advance. This worked very well. I took questions through the chat box and live after the movie was shown. The presentation is available for anyone who requests it via: lawrence.p.forsley@nasa.gov

IE: What did you conclude in your comparison between LENR and hot fusion?
LF: I think LENR has a better chance of commercialization than any of the hot fusion prospects, save for the Sun!

Hot fusion has embraced the Lawson Criteria that assumes a plasma temperature of at least 5 keV (55 million °C) and attempts to balance plasma, or ionized deuterium-tritium gas, heating and losses, fusion cross sections and ion density. A simpler expression, the "fusion triple product," multiplies the plasma density, temperature and confinement time as a "figure of merit." I applied these criteria to LENR or, as Nee and others[1] have termed, "lattice confinement fusion" (LCF). My first crack at this indicated a fusion triple product 100,000 times larger than the best magnetic fusion value observed in 2018 at the Japanese JT-60U tokamak. One of the conference attendees took issue with my interpretation of Lawson, and we have corresponded.

In particular, I think the role of electron screening is under-appreciated. However, it requires electron densities orders of magnitude larger than occur in magnetic fusion plasmas, so its absence from "the equation" is reasonable. Yet, electron screening occurs in LENR, which has a nuclear fuel and electron density high enough for strong screening to occur. Strong electron screening occurs in Fermi degenerate matter, which holds up white dwarf stars, and in metals.

I'm exploring a "fusion quad or quint product" to better compare different means of driving fusion reactions, whether cold or hot! Ultimately, the ability to confine fusion fuel in an electron-screened lattice (LCF) without superconducting magnets (MCF) or triggering it with large lasers (ICF) is more likely to succeed. Or a combination of LCF and MCF may prevail.

IE: Can you walk us through the major points of your talk?
LF: I had four major parts: Conventional Fusion; Fusion in an Unconventional Place; Electron Screening and Modeling; Pd/D Co-Deposition Protocol. These had three takeaways: Fusion occurs in unconventional places but 1) requires high hydrogen isotope density and flux; 2) is enabled by lattice electron screening and 3) is sometimes aneutronic.

Fusion modeling is important to astrophysics, conventional fusion, unconventional fusion and fusion triple product comparisons.

The Pd/D co-deposition protocol works. See U.S. Patent 8,419,919 (2013, "A System and Method to Produce Energetic Particles"). The process is repeatable, reproducible and safe. It has been replicated more than 1,000 times in multiple countries, with over 60 peer-reviewed papers from 14 countries.

In the presentation I contrasted three forms of fusion: Inertial Confinement, or Laser, Fusion (ICF); Magnetic Confinement, or tokamak, Fusion (MCF); and Lattice Confinement Fusion (LCF) using co-deposition. See Figure 1.

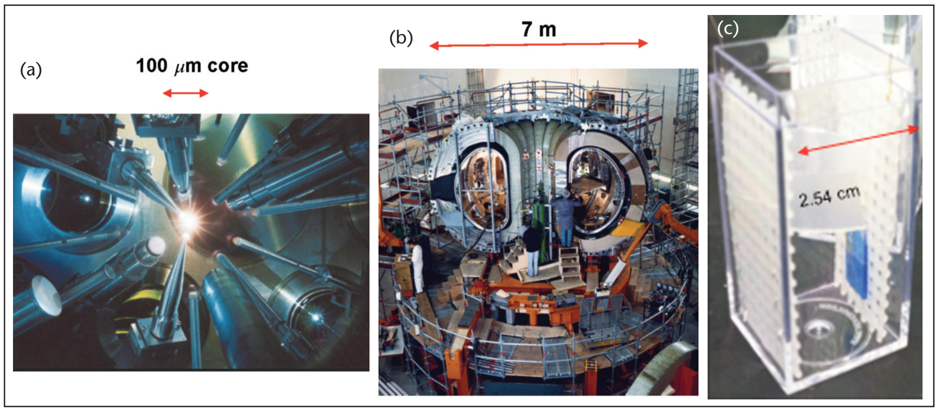

Figure 1. Three forms of fusion: (a) Inertial confinement. University of Rochester, Omega laser system; (b) Magnetic confinement. ASDEX upgrade tokamak during construction in 1989, courtesy of the Max Planck Institut fur Plasmaphysiks; (c) Lattice confinement (co-deposition).

IE: You mentioned lattice confinement fusion (LCF) in your talk, which is a term used on a NASA website.[2] Can you tell us how the the LCF work began at NASA?
LF: I met Dr. Alexi Didyk, from the Joint Institute for Nuclear Research in Dubna, Russia, at ICCF17 in South Korea in August 2012. Sadly, Alexi passed away in 2016. His group used an electron accelerator to produce gamma rays from a braking target to "excite" and then fission deuterated palladium.[3] We began a series of related experiments at NASA that we published as technical memos and journal papers. Although clearly not LENR as they occur at temperatures in the hundreds of millions of degrees, these experiments provide experimental and theoretical understanding of a variety of fusion reactions that extend into the low-temperature LENR régime. We published our results on LCF in a pair of papers in the journal *Physical Review C*[4,5] in January 2020 with publicly available versions as NASA Technical Papers.[6]

IE: What was your role at NASA?
LF: I was the senior lead experimental physicist for the NASA Advanced Energy Conversion Project that explored a variety of ways to load deuterium and trigger LENR. In addition to the NASA Technical Memos and *Physical Review C* papers, we published "Transmutations Observed from Pressure Cycling Palladium Silver Metals with Deuterium Gas" in the *International Journal of Hydrogen Energy*.[7] More recently the paper "Electrolytic Co-deposition Neutron Production Measured by Bubble Detectors" was published in the *Journal of Electroanalytical Chemistry*.[8] These papers note a drop in temperature from hundreds of millions of degrees using bremsstrahlung gamma rays to trigger LCF to far lower temperatures with both the deuterium gas cycling and room-temperature co-deposition experiments. Both of these papers show evidence of LENR nuclear activity: one by transmutations and the other by fast neutron detections. LCF and LENR are related through hydrogen isotope loaded lattices and electron screening.

IE: For readers unfamiliar with the term, what is co-deposition?
LF: Dr. Stan Szpak, with Dr. Pamela Mosier-Boss at U.S. Navy NOSC (renamed SPAWAR-Pacific and now NIWC), developed a means to electrolytically build palladium/deuterium lattices that wouldn't crack while loading. Bulk palladium loaded with hydrogen or deuterium expands a few percent, creating cracks allowing deuterium to escape. But by simultaneously reducing palladium and deuterium together an expanded lattice forms without cracking. Pam and I published an undergraduate student guide on how to run co-deposition and measure the nuclear effects in the *Journal of Laboratory Chemical Education*.[9] (This guide has been viewed or downloaded over 3,000 times.) Additionally, Chapter 2, "Review of Pd/D Co-deposition," from the book *Cold Fusion: Advances in Condensed Matter Nuclear Science*,[10] discusses the protocol.

I believe 1,000 successful replications of the protocol, and its modifications, have occurred in U.S. Government laboratories and universities, with private researchers and in several countries. This is the basis of our Trackers STEM Program™ supported by the Anthropocene Institute and Global Energy Corporation.

IE: What is Trackers?
LF: The Trackers Program teaches undergraduate students and faculty about LENR, or LCF, through co-deposition experiments that can be performed in a semester. This has been conducted by multiple chemical engineering students and by a single physics student, at two different universities.

The Horizon 2020 CORDIS HERMES Project "Breakthrough Zero-emissions Heat Generation with Hydrogen-metal Systems," coordinated by Turun Yliopisto (University of Turku) in Finland, successfully used the protocol described in this paper with CR-39. CR-39 is a solid state nuclear track detector (SSNTD) used in laser fusion, on the International Space Station and for personal neutron detection. Charged particles, like fast protons and alphas, and neutron recoils within the CR-39, leave nanometer size tracks that can be etched, then viewed and measured under a microscope. Hence, the name of the Trackers program.

IE: What is electron screening and why does it matter to LENR?
LF: Electron screening was recognized in 1954 by Salpeter[11] as important to astrophysics. He described weak and strong electron shielding of charged particles that reduced the Coulomb barrier between them and consequently increased fusion rates. Later, Bystritskii *et al.*,[12] Rolfs *et al.*,[13] Huke *et al.*,[14] Czerski,[15] Raiola *et al.*,[16] Kasagi[17] and others practiced "laboratory astrophysics" by firing deuteron beams against targets. These experiments began in the late 1980s simultaneous[18] with Fleischmann and Pons' "cold fusion" research. Increasingly these researchers found modest energy, accelerated deuterons induced fusion in condensed matter, including metals. However, the fusion rates were orders of magnitude higher than was expected between bare nuclei in a hot, gaseous plasma, as indicated in Figure 2.

Figure 3 shows that electron screening occurs in room temperature metals, the cores of planets like Jupiter and the centers of stars; provided there is a high density of electrons. Our *Physical Review C* theoretical paper[5] denotes four forms

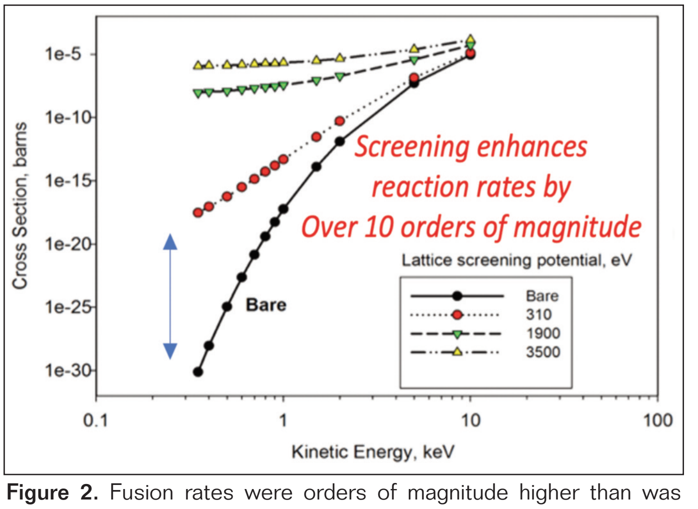

Figure 2. Fusion rates were orders of magnitude higher than was expected between bare nuclei in a hot, gaseous plasma.

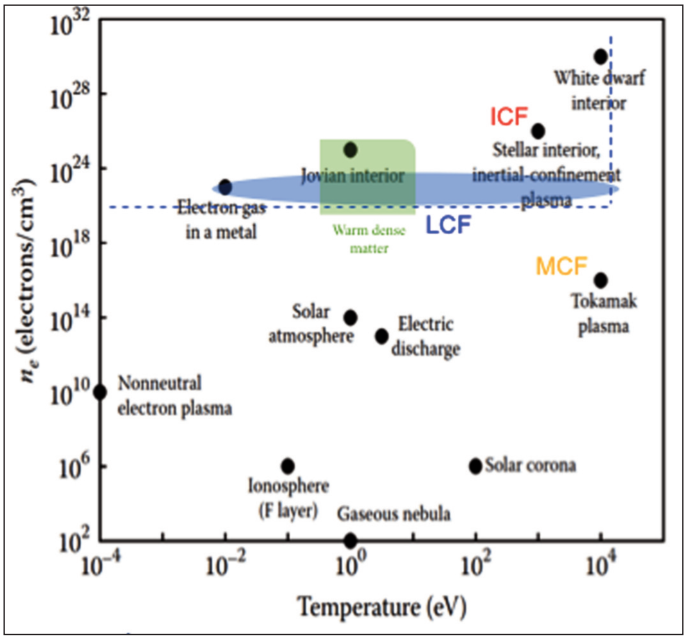

Figure 3. Examples of electron density vs. temperature.

of electron screening: lattice electrons, plasma particles, conduction electrons and shell (bound) electrons. Unexpectedly, screening increases fusion rates exponentially at ever lower energies. These apply to LENR. Indeed, some researchers have found screening provides the equivalent of over 3 keV, or to 33 million °C of deuteron kinetic energy, equaling what many tokamaks operate at! We refer to this as locally hot, but globally cold.

IE: Why is NASA interested in LENR or LCF?
LF: NASA has successfully used radioisotope power systems for over five decades for missions throughout the solar system. For example, both the Curiosity and Perseverance, aka Percy, Mars rovers have "nuclear batteries." The two Voyager spacecraft that launched in 1977 continue to operate after 44 years, a little over half of the half-life of the heat source Pu-238's alpha particle decay, and are now in interstellar space! However, radioisotope thermoelectric generators (RTGs) have been limited to producing less than 1 kilowatt of electrical power and usually only produce a few hundred watts. Consequently, for decades NASA has looked into fission and fusion reactors, and for the past several years LCF, to provide higher power output for future deep space missions.

IE: Is NASA continuing this research?
LF: Yes, our research and development continues as the NASA Planetary Science Division, Lattice Confinement Fusion Project, on which I act as Co-PI with Dr. Theresa Benyo, the principal investigator.

Our Project goals are to find efficient means of triggering and scaling LCF and developing predictive modeling. Recently, Theresa and I gave a virtual presentation at a Los Alamos National Laboratory Symposium on Monte-Carlo N Particle (MCNP) Fusion Modeling of Electron-Screened Ions.[19] We noted the need to model fusion and how we plan to augment their existing MCNP nuclear code. Currently, neither MCNP nor the CERN GEANT-4 codes model fusion reactions, nor do they fully account for electron screening. Once we can model electron screened fusion we should be able to predict the materials and triggers that give us the best results.

IE: Returning to ICCF23, what did you think about the presentations?
LF: I was disappointed that much of what was presented had been conducted years ago. For example, the Google Research group's findings by Matt Trevithick, Dr. Graham Hubler at the University of Missouri SKINR Center, and Dr. David Nagel's and Dr. Michael McKubre's overviews of decades of work. We learned the Google Research group was named "Charleston" after the Google HQ street where the group started. However, Matt Trevithick stated that the plasma discharge experiments conducted by Dr. Thomas Schenkel's group at Lawrence Berkeley National Laboratory (LBNL) weren't "cold fusion," as they saw fast neutrons. This was more completely discussed in "Investigation of Light Ion Fusion Reactions with Plasma Discharges,"[20] where they attributed an increased fusion rate to electron screening in the deuterated palladium lattice.

Dr. Ed Storms described his recent work creating LENR compressed powders and observing excess power. Dr. Fran Tanzella reported on both his analyses of Brillouin's system, including THz multi-spectral imaging, and earlier work at SRI, including the Arata double-cathode. Dr. Yasuhiro Iwamura cited the 1989 gas cycling of Dr. Gustave Fralick at NASA as significant to his work, as did Dr. Hang Zhang who replicated Dr. Tadahiko Mizuno's earlier research. Gus Fralick and his colleagues published more recent results in the aforementioned paper.[7]

Dr. Tie-Shan Wang conducted ion beam experiments citing Dr. Jirohta Kasagi's earlier published results. Dr. Wu-Shou Zhang replicated Mizuno's experiment using palladium alloys he received from Dr. Mel Miles. Miles reviewed his results with the palladium-boron alloys he developed and patented with Dr. Ashraf Imam at the Naval Research Laboratory. Dr. Roger Stringham reported on his earlier cavitation research and the detection of helium by Dr. Brian Oliver at Pacific Northwest National Laboratory (PNNL).

There was some confusion during my presentation regarding the solid state nuclear track detector, CR-39. Specifically, it does not detect thermal neutrons unless it has enriched boron ^{10}B which captures nearly thermal neutrons, resulting in an energetic alpha particle and a lithium ^{7}Li recoil. Both leave tracks in the CR-39. Although a very efficient fast ion detector, it is a poor fast neutron detector.

IE: Any other general thoughts on ICCF23?
LF: McKubre, Nagel and others stated that publications are scanty. They restated the need for a repeatable and replicable LENR protocol, or as Matt Trevithick called it a "reference experiment." This has been groused about at multiple ICCF conferences. Yet, Pam Mosier-Boss and I find this fallacious. As noted earlier, co-deposition has been used and repeated hundreds of times across the globe. We and over 60 colleagues from 14 countries have published 63 peer-reviewed papers, and two co-deposition patents have been granted.

Dr. Zhong-Qun Tian invited over 100 students to the conference, though I don't know how many participated. He and I discussed the problem of students, faculty and academia studying this field in China as it is in the United States and elsewhere. Years ago, Dr. Frank Gordon was told by an editor at the journal *Nature* that they wouldn't accept papers on this phenomena until DOE accepted it. Several of us have learned from DOE that they won't accept the field until it's published in *Nature*: Catch-22! We discussed this in a 2013 paper.[21]

However, the Google Research results were published in *Nature* in 2019,[22] as discussed by Trevithick. One can suspect *Nature* published the paper because it described 420 failed experiments but it also had a paragraph on the successful LBNL low energy plasma discharge-induced fusion results.

Some of us asked the organizers to keep the chat and Zoom open during the lunch and dinner breaks. Then various groups of us conversed outside of the sessions much as we would during breaks during an in-person meeting. After the conference ended, and people left, the Zoom call was left open and eventually several of our colleagues across Russia had the opportunity to chat amongst themselves. Sadly, the Zoom call closed after about 15 minutes, but it was very sweet. Indeed, much of the importance of conferences in general occurs in these chance and deliberate gatherings.

I was pleased to learn that Carl Page will chair ICCF24 in 2022 in the San Francisco, California area. He has been a long-time supporter of the field and of companies and individuals working on LENR.

IE: Where do you think the field should go from here?

LF: If you accept that multiple Japanese researchers using encapsulated Pd and PdNi nanoparticles consistently produce excess heat, that co-deposition is a suitable lab rat, or that other systems exist, then it's high time we move from replication to scaling. Without scaling, and system gain, we'll never reach a self-powered system. As a rule of thumb, if one is converting thermal energy to electrical energy, then at least 10x the thermal energy is required, let alone what's necessary to drive the reactor. That also suggests a high enough delta-T, or the temperature difference between the reaction and the cold sink, to allow efficient thermal to electric conversion. The planet doesn't need another source of low-grade heat!

A couple of years ago McKubre noted that constant-temperature bath calorimeters, typically operating around 30°C to accurately detect small amounts of heat, might inadvertently limit LENR reactions that become increasingly exothermic at higher temperatures. This was observed by Dr. Martin Fleischmann and Dr. Stanley Pons while working in Valbonne, France, but earlier by them and others as well. I've advised some of the groups I work with to follow this advice.

Once we have a self-powered system, we're finally on our way to a useful technology and its commercialization. There are several promising experiments that will come out of the European Union Horizon 2020 CORDIS projects, including a presentation by Dr. Konrad Czerski at ICCF23. These seem to nibble at the edges of replicating experiments then scaling the output. Similarly, DOE ARPA-E issued an RFI (Request for Information) for a possible program in "unconventional fusion."

In my talk I emphasized the power of the lattice, as had the late Nobel Laureate, Dr. Julian Schwinger. He said in a 1991 talk at MIT (published in *Infinite Energy* Issue 24 in 1999), "Unlike the near-vacuum of HF [Hot Fusion], the ambient environment of cold fusion is the lattice, which is a dynamical system capable of storing and exchanging energy."

I ended my talk with a brief video I shot of Dr. Martin Fleischmann in his home in Tisbury, UK in 2007. Martin admonished us that, "The status is as before. We know a lot more about the system but not enough. Not enough to bring it to a satisfactory conclusion. So keep going!"

We will!

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Lawrence Forsley was the senior lead experimental physicist on the NASA Glenn Research Center Advanced Energy Conversion Project and is Co-PI of the NASA Planetary Exploratory Science Technology Office (PESTO), Lattice Confinement Fusion Project. He is a research fellow at the University of Texas, Austin, Nuclear Engineering Teaching Laboratory; Co-PI with the Naval Surface Warfare Centers and previously U.S. Navy SPAWAR-Pacific; and CTO of Global Energy Corporation. During the past 45 years, he has developed control and diagnostic systems for fusion research at the University of Rochester Laboratory for Laser Energetics (Group Leader, Omega laser fusion), Lawrence Livermore National Laboratory (consultant, TMX-U/MFTF-B mirror fusion) and Max-Planck-Institut für Plasmaphysiks (visiting scientist, ASDEX tokamak) as well as for a modular bremsstrahlung source for the Defense Nuclear Agency. As PI he observed time-resolved, sonoluminescence-induced gamma rays at the Naval Research Laboratory and has specialized in temporally, spatially and spectrally resolving infrared through gamma ray energy photons, charged particles and neutrons. He was a lecturer at the University of Rochester, and lectured on nano-nuclear reactions at the Université catholique de Louvain, Louvain-la-Neuve, Belgium and the Korea Advanced Institute of Science and Technology (KAIST), Daejeon, South Korea.

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