A closer look at Widom-Larsen theory of LENRs in condensed matter

300 nanoseconds in the life of a µ-scale LENR-active surface 'patch'

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The following information may be helpful insofar as providing insight into the 100-year 'checkered' history of LENRs as well as a much more detailed working knowledge of how LENR-active 'patches' operate on condensed matter surfaces where Born-Oppenheimer breaks down and the otherwise distant chemical and nuclear energy realms can, under exactly the right conditions, occasionally come together.

Preface: let me preface my remarks to follow by noting that, according to a theory developed by Prof. Dave Seidman of Northwestern University (Director, Center for Atom-Probe Tomography, Evanston, IL), prosaic, small-length-scale electron field emission processes on surfaces are almost invariably accompanied by some degree of surface breakdown and production of ejected charged/uncharged nanoparticles, i.e. 'dust.' In addition, Dr. Andre Anders of Lawrence Berkeley National Laboratory (who has done interesting work on cathodic arcs) has gone one step further and proposed an even more energetic type of "*arc spot ignition*" event which he describes as a (quoting him directly), "*Local thermal run-away process [that] leads to micro-explosion and formation of extremely dense plasma.*"

Electric field strengths and effective power densities can get surprisingly large on nanometer to micron length-scales on and around nanostructures located on surfaces; quoting Dave Seidman, *"Another interesting feature of this [electrical breakdown] mechanism is that the power densities involved are enormous. The numbers can be obtained from the values we measured for field emitted currents, electric field, the emitter dimensions, and volume for transferring electromagnetic field energy into electron kinetic energy. Combining these gives, $(10 \text{ GV/m})(10^{-7} \text{ m})(1 \text{ mA})/(10^{-7} \text{ m})^3 = 10^{21} \text{W/m}^3$, a value that seems to be greater than all other natural effects, except perhaps Gamma Ray Bursters (GRB"s). The power density is comparable to nuclear weapons."* Length-scale matters!

Details about all of the above items are explained in **Slides #11 – 31** (as well as SEM-image-based morphological comparisons between 'prosaic' cathodic arc surface 'craters' and LENRs) in the following online Lattice PowerPoint presentation dated July 16, 2010 (can be viewed online in 'full-screen' mode or downloaded after a perfunctory free registration):

"Low Energy Neutron Reactions (LENRs) in Advanced Batteries and Other Condensed Matter Environments --- Could LENRs be involved in some Li-ion battery fires?"
http://www.slideshare.net/lewisglarsen/cfakepathlattice-energy-llc-len-rs-in-liion-battery-firesjuly-16-2010

Widom-Larsen theory of LENRs - short recap: beyond Anders' plausible runaway mechanism, under exactly the right conditions (contiguous many-body monolayer 'patch' of entangled, collectively oscillating protons on a surface + entangled collectively oscillating surface plasmon electrons + local breakdown of Born-Oppenheimer approximation + nonequilibrium energy input) and when local *nanoscale* E-fields in a 'patch' exceed $\sim 2 \times 10^{11}$ V/m, then some number of the surface plasmon electrons located in such a "patch" will have high-enough renormalized masses to react directly with 'nearby' protons in a weak reaction: $e + p \rightarrow neutron + electron\ neutrino$. Collectively produced neutrons will have extremely large DeBroglie wavelengths (depend on dimensions of a given 'patch; from ~ 2 *nm* to perhaps ~ 100 *microns*) and will be captured locally within picoseconds (they generally don't have enough time to thermalize which requires a few tenths of a millisecond); prompt and delayed gammas between $\sim 0.5 – 1.0$ MeV up through 10 - 11 MeV resulting from captures or subsequent decay processes are locally converted directly into infrared photons by the population of unreacted, entangled heavy electrons present in a 'patch' ('tail' in soft X-rays; again, please see: *"Absorption of Nuclear Gamma Radiation by Heavy Electrons on Metallic Hydride Surfaces"* (Sept 2005), A. Widom and L. Larsen at http://arxiv.org/PS_cache/cond-mat/pdf/0509/0509269v1.pdf).

Under most 'normal' circumstances in Nature, LENRs are relatively rare processes: under 'normal' circumstances in Nature and in the vast majority of typical laboratory experiments LENRs clearly do not occur very often --- maybe only rarely in a minuscule percentage of even favorable microenvironments and at relatively low rates therein. Otherwise, for example, our earth would probably be a hostile, much different, hotter place --- perhaps a molten ball of incandescent lava in a perpetual state of LENR-driven chemical element chaos (as opposed to the temperate, water-rich world teeming with life in which we presently exist that is comprised of predominantly long-lived isotopes having relatively stable planetary abundances, at least over non-geological time horizons).

Key reasons why LENRs have a checkered, controversial 100-year history: it presently appears that a myriad of different experimentalists have episodically observed and discovered, discarded and forgotten, and subsequently re-discovered various aspects of anomalous LENR-related phenomena for at least 100 years. The first period of discovery occurred from the late 1880s through ~1930; there was another spate at Cornell University in the early 1950s in which Hans Bethe and even Einstein got involved; an unpublished 'blip' that occurred at the University of Florida in the mid-1960s; and finally the latest saga that began with Pons & Fleischmann's (P&F) Utah debacle in 1989 and continues today. *Who knows how many other LENR-related discoveries around the world went unreported up until now?*

In many cases, researchers simply had no idea what they were really seeing in their measurements; many scientists commonly discarded, ignored, or simply disbelieved otherwise good data and neglected to follow-up on puzzling results with further investigation because they thought (not unreasonably) that the seemingly anomalous observations must somehow be erroneous in one way or another. Even when there were no obvious flaws in such data, in many cases the anomalous effects were hit-or-miss and quite difficult to accurately reproduce; there was no readily discernible payoff for anybody in pursuing a new mystery any further (let alone the potential danger to one's scientific career). Lastly, none of such observations made any conceptual sense from a theoretical perspective in the context of widely accepted theory available when such measurements were first presented at conferences or published in journals.

There are multiple reasons for this long, 'checkered' history. One of the most important is that LENR signatures in condensed matter systems are relatively subtle; they characteristically do not produce obvious, potentially lethal radiation emissions that unequivocally announce their presence. That is, there are no large fluxes of MeV-energy gamma photons and/or thermalized to MeV-energy neutrons that can be externally detected and measured in running experiments that are simultaneously producing significant amounts of calorimetrically-measured 'excess heat' (indeed, this is the basis of the "*dead graduate student problem*" that skeptics raised with P&F back in 1989 - 90). P&F's obviously naive and physically nonsensical D-D "*cold fusion*" hypothesis made matters even worse as far as the believability of their experimental claims (which involved production of excess heat and He-4) was concerned.

Mass spectroscopy probably the best analytical technique for diagnosing presence of LENRs: by the early to mid-1990s maverick LENR researchers located at a smattering of major universities and national laboratories in Japan, Russia, Italy, and the US were already doing competent before-and-after analyses of experimental LENR devices using various types of mass spectroscopy and (mainly at conferences) reporting the appearance of many new elements not initially present at the beginning of experiments and/or substantial isotopic shifts in stable isotopes of elements initially present that could not reasonably be explained by contamination and/or the action of prosaic chemical isotopic fractionation processes. *Hard-core cold fusioneers who worshiped the "cold fusion" paradigm ignored these results.*

Some apostate LENR researchers using SIMS to assay isotopes post-experiment were even able to spatially correlate elemental or isotopic anomalies with distinctive morphological features observed on post-experiment metallic device surfaces: unusual structures found at such locations often consisted of micron-scale 'craters' and other odd morphologies indicative of locally explosive 'flash melting' or 'boiling' events. *Indeed, it was Prof. George Miley's (Dept. of Nuclear Engineering, Univ. of Illinois at Urban-Champaign) distinctive 5-peak Ni/H_2O transmutation product mass-spectrum published in 1996 (mostly SIMS and neutron activation analyses data) that convinced me to begin looking into LENRs in mid-1997.*

Widom & Larsen explain distinctive LENR product mass spectra: in 2006, Allan Widom and I finally explained Miley & Mizuno's observed 5-peak product mass spectra with a simple 2-parameter ULMN 'optical' absorption model using no data-fitting in *"Nuclear Abundances in Metallic Hydride Electrodes of Electrolytic Chemical Cells"* at: http://arxiv.org/PS_cache/cond-mat/pdf/0602/0602472v1.pdf

Measuring macroscopic 'excess heat' with calorimetry presently the worst diagnostic for LENRs: a second key reason for the checkered history of LENRs, particularly in the years since1989, has been the pernicious effects of cold fusioneers' dominant conceptual paradigm that D + D → He-4 + heat (CFers 'hand-wave' about how an ~23 MeV gamma magically gets converted into heat), which most researchers then naively assumed was the *only* nuclear reaction occurring in their experimental systems. Uncritical acceptance of this fatally flawed paradigm by the vast majority of LENR researchers had the unfortunate effect of guiding and shaping their experimental work in ways that were extremely unproductive with regard to being able to achieve substantial R&D progress over time (especially with regard to improving reproducibility and scale-up of potentially useful thermal effects), even with very limited funding.

Three unhelpful 'tribal myths' accompanied CFers' quasi-religious belief in the "*D-D cold fusion*" paradigm: (1) LENRs are a bulk effect and occur throughout the interior of a metallic hydride lattice (erroneous; *according to WLT LENRs in condensed matter are predominantly surface or near-surface phenomena that occur only in discrete, widely-scattered micron-scale 'islands' that are LENR-active*); (2) since readily detected high-energy neutron and gamma signatures of nuclear processes were clearly absent, according to cold fusion dogma the *only* LENR reaction products that needed measurements were gaseous He-4 using mass spectroscopy and accompanying heat production using calorimetry (erroneous; *WLT posits that ULM neutron-catalyzed nucleosynthetic networks can produce many different transmutation products, which have clearly been observed by the tiny minority of apostate LENR researchers who actually bothered to perform exhaustive post-experiment analyses using mass spectroscopy*); and (3) LENRs are strictly the result of somehow unique physical, structural, and materials properties of pure elemental Palladium-Deuterium system that are supposedly not possessed by any other element, alloy, or compound; (this initially dogmatic view began to 'relax' *ca.* 2000 when it became obvious to many workers within the field that excess heat and transmutations could also be triggered in Titanium and Nickel using either Deuterium or Hydrogen (erroneous: *WLT predicts that LENR phenomena can occur in many different types of condensed matter systems under conditions specified by the theory; this includes various environments in which surface plasmon electrons are present in conjunction with surface 'patches' of hydrogenous ions at metal/dielectric interfaces subjected to certain types of non-equilibrium energy inputs; according to my further extensions to WLT developed since late 2008, LENRs may also occur on organic molecular aromatic, e.g. benzene, rings and polycyclic aromatic hydrocarbons, i.e. PAHs, and perhaps even in NH_4^+ ions as explained on* **Slides # 42 – 48** *found in:* http://www.slideshare.net/lewisglarsen/lattice-energy-llctechnical-overviewpahs-and-lenrsnov-25-2009*)*.

The end-result of the "cold fusion" belief system was that, except for a handful of LENR researchers who had sufficient funding and technical skills to perform competent He-4 measurements and an equally small group that tried to exhaustively measure transmutation products with mass spectroscopy, perhaps 80 - 90% of all experimental man-hours expended since 1989 were devoted simply to calorimetric measurements of excess heat in current-driven P&F Pt anode/Pd cathode Lithium-salt D_2O aqueous electrolytic cells. With no detailed theory to guide them, these researchers explored LENRs by blindly varying various types of experimental parameters with increases in observed macroscopic excess heat as the only clear metric of 'success.' Not surprisingly, to date this unguided, random Edisonian approach to LENR R&D has failed to achieve readily reproducible, highly scalable thermal effects. This unfortunate outcome after 20+ years of effort happened because in addition to the twin problems of the D-D fusion hypothesis being totally wrong and very limited levels of funding, most LENR researchers were and are still unaware of certain key technical knowledge derived from nanotechnology, plasmonics, and materials science that, according to WLT, must be both mastered and successfully applied in order to be able to fabricate reproducible, well-performing condensed matter LENR devices. *To be fair, it should be noted that such technical knowledge did not even exist in 1989, or even in the mid-to-late 1990s. In my view, there is no way condensed matter LENRs could have been truly experimentally reproducible prior to the past several years. That said, commercialization may now finally be feasible thanks to experimental and engineering guidance provided by WLT and its unpublished, proprietary extensions.*

Rates of LENRs can be increased substantially in non-natural environments: fortunately, using conceptual insights provided by the WLT, experimental conditions in condensed matter systems and 'dusty' plasmas can be technologically 'tweaked' to increase rates of weak reaction neutron production far above whatever levels might ever be attainable in analogous systems found at random out in Nature or in the vast majority of LENR laboratory experiments conducted to date.

Technologically, many-body collective electroweak neutron production rates can be manipulated by: (1) controlling total numbers and density of e^-p^+ pairs on a given surface (which is ~equivalent to controlling the area-density and dimensions of many-body, collectively oscillating surface 'patches' of protons or deuterons); and (2) controlling the rate and total quantity of appropriate form(s) of nonequilibrium energy input into LENR-active 'patches'; appropriate forms of input energy can go directly into high electric fields that 'bathe' SP electrons in a 'patch' --- it determines the number and effective masses of e^* electrons present in a given 'patch' whose increased masses are at values somewhere above the minimum mass-renormalization threshold ratio, β_0 that is required for initiating $e^* + p$ or $e^* + d$ weak reactions. The term $(\beta - \beta_0)^2$ in our published rate equation reflects the degree to which mass renormalized e^* electrons in a given 'patch' *exceed* the minimum threshold ratio for neutron production β_0. Details of this are explained in our first principles ULM neutron production rates calculation paper found on the Cornell arXiv at: http://arxiv.org/PS_cache/nucl-th/pdf/0608/0608059v2.pdf.

Simply put, all other things being equal, the higher the density of e^-p^+ reactants and the greater the rate and quantity of appropriate forms of nonequilibrium energy input, the higher the rate of ULM neutron production in µ-scale LENR-active 'patches' in an appropriately pre-configured condensed matter system.

Importantly, it is known within the field that, under exactly the right conditions and in a number of different types of experimental systems (e.g., rare *well-performing* current-driven aqueous H_2O/D_2O electrolytic chemical cells), rates of transmutation product production (which according to WLT are very closely related to parallel rates of many-body, collective weak reaction ULM neutron production) can be quite substantial. Measured indirectly via qualitative and quantitative assays of LENR transmutation products, estimates of experimentally observed, effectively neutron production rates reported by LENR researchers range from ~10^9 - 10^{10} cm^2/sec up to ~10^{12} - 10^{16} cm^2/sec in some very well-performing systems.

In 2007, Allan Widom and I published first-principles calculations which show that substantial ULM neutron production rates via such electroweak reactions are theoretically possible in condensed matter systems under such 'mild' conditions; calculated results for such rates in a model electrolytic chemical cell (on the order of 10^{12} to 10^{14} neutrons cm^2/second) are thus in good agreement with the best available published experimental data: http://arxiv.org/PS_cache/nucl-th/pdf/0608/0608059v2.pdf.

300 nanoseconds in the life of a *µ*-scale LENR-active surface 'patch' in condensed matter: as best we know, LENR-active surface sites in condensed matter are not permanent entities. In experimental or certain natural systems with sufficient input energy, when conditions are just right they will form spontaneously, operate for as little as 10 *ns* up to perhaps several hundred nanoseconds, and then suddenly 'die' (they effectively destroy themselves). Over time or the course of a given experiment, many cycles of 'birth', nuclear binding energy release, and 'death' may be repeated over and over again at many different, randomly scattered *nm*-to-*micron*-sized locations found on a given surface or interface; neutron-dose histories can vary greatly over small length-scales across an entire LENR-active surface. Such spatial elemental/isotopic heterogeneity has often been observed by LENR researchers with SIMS.

While ULM neutron production and local capture, gamma conversion to IR by heavy electrons, and subsequent nuclear decays are occurring, these tiny 'patches' temporarily become 'hot spots.' Their temperatures may briefly reach 4,000 - 6,000^{o}K or perhaps even higher. That value is roughly as high as the 'surface' temperature of the Sun and hot enough to melt and/or even flash boil essentially all metals and alloys, including Tungsten (b.p. = 5,666^{o}C). For a brief time, a tiny dense 'ball' of very hot, 'nanodusty' plasma is created. Such intense local heating events can produce various types of distinctive explosive melting features and/or comparatively deep 'craters' that are often observed in post-experiment

SEM images of LENR device surfaces (for Zhang & Dash's image of such surface features see **Slide #69** in http://www.slideshare.net/lewisglarsen/lattice-energy-llctechnical-overviewjune-25-2009).
ULM neutron production can begin in a given many-body 'patch' after local E-field strengths exceed 2 x 10^{11} V/m (i.e., e^* mass renormalization ratio β is now greater than the minimum threshold ratio β_0) and an adequate number of mass-renormalized e^* electrons have been created (enabled by local breakdown of the Born-Oppenheimer approximation in ~temporal conjunction with nonequilibrium energy inputs).

As best we know, the $e^* + p$ or $e^* + d$ weak reactions appear to occur during many-body, collectively oscillating protons' brief moments of quantum coherence (i.e., effective entanglement within a 'patch'); duration of such proton coherence times are on the order of attoseconds (~10^{-18} sec; measured by Chatzidimitriou-Dreismann, 2005, cited in **Slide #44** in http://www.slideshare.net/lewisglarsen/lattice-energy-llctechnical-overviewpahs-and-lenrsnov-25-2009). Once the e mass renormalization 'set-up' process has completed and heavy e^* electrons and p^+ protons are finally ready to react (i.e., β now $> \beta_0$), subsequent weak reactions that follow only require ~10^{-19} to 10^{-22} sec to finish. *Thus, while 'flickering' proton coherence times are relatively short, weak reactions that act to produce ULM neutrons operate on even faster nuclear time-scales, thus allowing local neutron production to proceed at substantial rates.*

Local neutron capture processes, especially when collectively produced neutrons are ULM, occur over time-horizons on the order of picoseconds (10^{-18} sec). It should also be noted that all of the many atoms located within a 3-D region of space that encompasses a given ULM neutron's spatially extended DeBroglie wave function (whose dimensions can range from 2 *nm* to 100 *microns*) will 'compete' with each other to capture such neutrons. *ULM neutron capture is thus a decidedly many-body scattering process*, not few-body scattering such as that which characterizes capture of neutrons at thermal energies in condensed matter in which the DeBroglie wave function of a thermal neutron is on the order of ~ 2 Angstroms. *This explains why the vast majority of produced neutrons are captured locally and not commonly detected at any energy during the course of experiments; it also clearly explains why lethal MeV-energy neutron fluxes are characteristically not produced in condensed matter LENR systems.*

Half-lives of the most neutron-rich, unstable beta-decaying isotopes are generally rather energetic and relatively short ---- often on the order of milliseconds (10^{-3} sec). For example, very neutron rich Nitrogen-23 is unstable to beta decay with a measured half-life of ~14.5 milliseconds and Q-value of ~23 MeV (see **Slide #12** in http://www.slideshare.net/lewisglarsen/lattice-energy-llctechnical-overviewcarbon-seed-lenr-networkssept-3-2009). Even so, ULM neutron capture processes generally occur at much faster rates than the decay rate of many beta- or alpha-unstable isotopes in LENR systems. If local ULM neutron production rates in a given 'patch' are high enough, this large difference in rates of beta decay vs. neutron capture processes means that populations of unstable, neutron-rich isotopes can potentially accumulate locally during the typical lifetime of an LENR-active patch, prior to destroying itself.

It should be noted that the Q-value for neutron capture on a given beta-unstable isotope can sometimes be *larger* than the Q-value for the alternative β^- decay pathway, so in addition to being a faster process than beta decay it can also be energetically more favorable. This can help to create local populations of neutron-rich isotopes. There is indirect experimental evidence that such neutron-rich isotopes can be produced in complex ULM neutron-catalyzed LENR nucleosynthetic (transmutation) networks that set-up and operate during the lifetime of a 'patch'; for example see the Carbon-seed network on **Slides # 11 - 12** and especially on **Slide #55** in http://www.slideshare.net/lewisglarsen/lattice-energy-llctechnical-overviewcarbon-seed-lenr-networkssept-3-2009 and a Tungsten-seed network segment on **Slide # 60** in http://www.slideshare.net/lewisglarsen/cfakepathlattice-energy-llc-len-rs-in-liion-battery-firesjuly-16-2010.

Beginning with so-called 'seed' or 'target' starting nuclei upon which ULM neutron captures are initiated, complex, very dynamically changing LENR nucleosynthetic networks are established in LENR-active 'patches.' These ULM neutron-catalyzed LENR networks exist for the lifetime of the particular 'patch' in which they were created; except for any still-decaying transmutation products that may linger, such networks typically 'die' along with the LENR-active 'patch' that originally gave birth to them. 'Seed' nuclei for such networks can comprise any atoms in a substrate underlying an LENR-active patch and/or include atoms located nearby in various types of surface nanoparticles or nanostructures that are electromagnetically connected to a 'patch.'

For an annotated example of a Carbon-seed LENR network please see **Slides # 11 - 12** in http://www.slideshare.net/lewisglarsen/lattice-energy-llctechnical-overviewcarbon-seed-lenr-networkssept-3-2009; for a Potassium-seed LENR network see **Slide # 57** in http://www.slideshare.net/lewisglarsen/lattice-energy-llctechnical-overviewjune-25-2009; for a Palladium-seed LENR network see **Slides # 52 - 53** in http://www.slideshare.net/lewisglarsen/lattice-energy-llcnickelseed-lenr-networksapril-20-2011; for a Nickel-seed LENR network see **Slides # 20 - 22** in http://www.slideshare.net/lewisglarsen/lattice-energy-llcnickel-seed-wl-lenr-nucleosynthetic-networkmarch-24-2011; and lastly for a Thorium-seed LENR network see **Slides # 3 - 4** in http://www.slideshare.net/lewisglarsen/thoriumseed-lenr-networkfigslattice-energydec-7-2010-6177745.

Per WLT, once ULM neutron production begins at high rates, populations of unstable, very neutron-rich 'halo' isotopes build-up locally in LENR-active 'patches' found on ~2-D condensed matter surfaces. As explained in **Slide #24** in http://www.slideshare.net/lewisglarsen/lattice-energy-llctechnical-overviewjune-25-2009), such nuclei likely have somewhat retarded decays because they can have a difficult time emitting beta electrons, neutrons, or even neutrinos (all of which happen to be fermions) into locally unoccupied fermionic states. Consequently, such unstable halo nuclei may often continue capturing ULM neutrons until they finally get so neutron-rich, or a previously occupied state in the local continuum opens-up, that 'something breaks' and spontaneous beta decay cascades ending in stable isotopes are initiated.

Key consequences of a unique situation that occurs in LENR-active 'patches' (very dense occupation of fermionic states in the local continuum) are that: (a) effective half-lives of very neutron-rich intermediates can sometimes be significantly longer than measured 'textbook' half-lives of comparatively isolated nuclei; and (b) % branching ratios for alternative β-delayed decay channels (e.g., unusual α-decay branches that occur in certain neutron-rich Nitrogen isotopes) that are normally available to such isotopes may change markedly compared to those of isolated nuclei. 'Normal' branching ratios may shift significantly if certain otherwise functional decay channels are temporarily blocked and unavailable; some decays can be 'frustrated' or delayed in 'patches' until unoccupied states open-up, for whatever reason.

Unlike stars, photodissociation or photonuclear reactions by energetic gammas ranging from ~0.5 up to ~10.0 MeV that can 'knock-off' loosely bound halo neutrons from unstable, extremely neutron-rich nuclei (thus hampering their quickly reaching higher values of A) are not much of an issue in condensed matter LENR transmutation networks, thanks to local gamma conversion *a la* WLT to IR by heavy e^* electrons.

Please also note that depending on half-lives of intermediate isotopes, β^- decay chain cascades can very rapidly traverse rows of the periodic table; thus, long-running LENR experiments with large ULMN fluxes can produce a broad variety of different stable elements in surprisingly short periods of time. For example, in one unrepeatable yet nonetheless spectacular experiment, Mizuno (Hokkaido University, Japan) went from Potassium (K) to Iron (Fe) in less than 2 minutes; see **Slides # 54 - 59** in http://www.slideshare.net/lewisglarsen/lattice-energy-llctechnical-overviewjune-25-2009.For examples of beta-decay cascades see **Slide #19** in http://www.slideshare.net/lewisglarsen/lattice-energy-llcnickel-seed-wl-lenr-nucleosynthetic-networkmarch-24-2011.

LENR transmutation network pathways comprising series of picosecond neutron captures interspersed with beta-decay cascades can release substantial amounts of nuclear binding energy, much of it in the form of usable process heat. For example, there is a multi-step LENR Carbon-seed pathway that can, in theory, release ~386 MeV over an 'average' period of ~3.4 hours. This total energy release is comparable to fission reactions (U-235 is ~190 MeV) but without any 'hard' neutron or gamma emission or production of long-lived radioactive isotopes; see **Slide #55** in http://www.slideshare.net/lewisglarsen/lattice-energy-llctechnical-overviewcarbon-seed-lenr-networkssept-3-2009

When nonequilibrium energy inputs creating large numbers of heavy electrons and ULM neutrons cease (e.g., electric current input going into an LENR electrolytic cell is turned-off completely) and/or when a given 'patch' reaches the end of its 'life' and destroys itself, large numbers of unoccupied fermionic states in the local continuum will then begin opening-up. This will then permit serial cascades of relatively fast chains of beta decays from unstable very neutron-rich intermediates all the way down to stable isotopes/elements; few long-lived radioisotopes would remain after such processes complete. *This is exactly why LENR-active 'patches' have a strong tendency to produce stable isotopes as end-products.*

Now that LENR-active patches are better understood, the commercialization process can begin:

Thus goes 300 nanoseconds in the 'life' of a micron-scale LENR-active 'patch' on a condensed matter surface. What is needed to create a commercially viable LENR technology is to achieve mastery over the fabrication, area-densities, reliable triggering, fine-scale control of reaction rates, and nucleosynthetic evolution of such 'patches;' this now appears to be feasible by applying presently available technologies.

Technologically speaking, weak interactions in LENR-active 'patches' aren't 'weak' energetically:
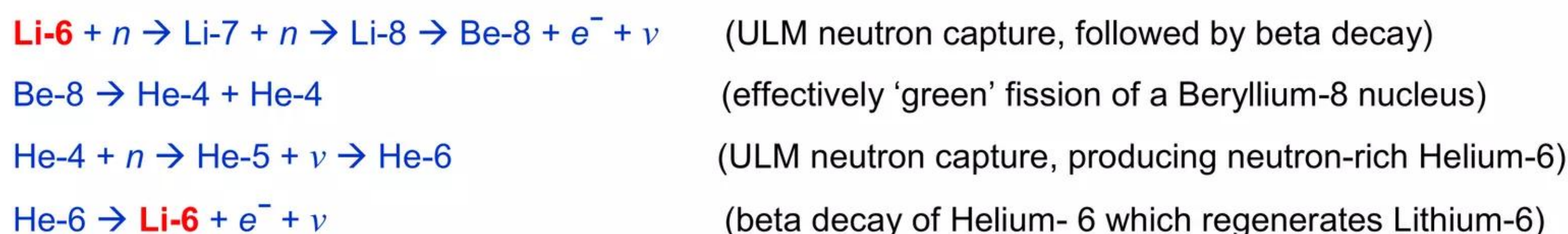
Contrary to naïve expectations, weak interaction LENRs are not necessarily 'weak' in terms of the total amount of energy released while traversing reaction network pathways. Widom & Larsen's 2006 *European Physical Journal C* paper shows the following Lithium-seed LENR network path:

<p align="center">Lithium-6 + 2 ULM neutrons → 2 Helium-4 + beta particle + neutrino + 26.9 MeV</p>

This particular LENR pathway can release about the same amount of energy as nuclear fusion processes without creating any energetic neutrons, hard gamma radiation, or radioactive isotopes. Although a portion of the 26.9 MeV in excess nuclear binding energy released is lost with the emitted neutrino, much of it still remains in the kinetic energy of the two helium atoms (which are low-energy alpha particles) and much more energetic beta particle.

In this particular case, local solid matter is heated-up by the scattering of low-energy alpha and much-higher-energy beta particles; heavy-mass electrons also present in LENR-active 'patches' convert any locally produced hard gammas or X-rays (from whatever process) directly into infrared heat.

Details of a LENR Lithium-seed nuclear cycle are (n = ULM neutron; beta particle = e^-; neutrino = ν):

Li-6 + n → Li-7 + n → Li-8 → Be-8 + e^- + ν (ULM neutron capture, followed by beta decay)

Be-8 → He-4 + He-4   (effectively 'green' fission of a Beryllium-8 nucleus)

He-4 + n → He-5 + ν → He-6   (ULM neutron capture, producing neutron-rich Helium-6)

He-6 → Li-6 + e^- + ν (beta decay of Helium- 6 which regenerates Lithium-6)

The above path comprises a nuclear 'reaction cycle' wherein stable Lithium-6 is regenerated as the final product; Lattice has uncovered other such LENR reaction cycles that release energy. Although LENRs occur in condensed matter at comparatively low temperatures and pressures, the above-listed reactions are conceptually analogous to the CNO cycle found in stars wherein the Carbon-12 nucleus, at which the stellar CNO cycle begins, is regenerated at the end of the cyclic process. While the stellar CNO cycle similarly releases ~27 MeV, it differs from the simple Lithium-seed LENR network shown above in that stellar CNO cycles involve primarily high-temperature, few-body strong interaction fusion reactions in hot plasmas rather than a combination of neutron captures and weak interactions in condensed matter.

Hypothetical energy releases from a small LENR device using a Lithium-6 reaction:

Note: *the following text was excerpted and slightly modified from part of a popular article that I wrote for the Institute of Science in Society (London, U.K.) titled, "Portable and Distributed Power Generation from LENRs," that was published online by I-SIS on December 10, 2008. Free version of the entire article is available at:* http://www.i-sis.org.uk/PortableDistributedPowerFromLENRs.php

To illustrate the tremendous commercial potential of LENRs for use in small, battery-like portable power generation systems (see below), we shall examine the maximum amount of energy that can be obtained from an idealized system. To simplify our calculations, we assume that conversion of input energy (in this case, an electric current) into energy available to produce LENR ULM neutrons is 100 percent efficient in order to estimate a *theoretical upper bound* on potential energy releases from a small LENR heat source.

We will also assume that 100 percent of the ULM neutrons produced in the hypothetical device are absorbed locally (a pretty safe bet that is supported by 20+ years of experiments) and that they are *only* absorbed by a 'target fuel' comprising isotopically pure Lithium-6, resulting in a series of nuclear reactions beginning with Lithium-6 and ending with Helium-4 (please see discussion above).

Lastly, we will assume that the 'base fuel' used to produce LENR ULM neutrons in our hypothetical device is *deuterium* and that it has an LENR-active working surface area of 1 cm^2.

The input energy required to produce 1 neutron/cm^2/sec from deuterium 'base fuel' to react with the Lithium-6 'target fuel' is 0.39 MeV per neutron. However, according to Eq. 1, we need two ULM neutrons to complete the entire series of reactions, so the required total input energy to the device is 0.78 MeV/cm^2/sec. The net energy release from that particular series of LENR reactions starting with Lithium-6 is 26.9 MeV/cm^2/sec = 4.28 x 10^{-12} J/cm^2/sec (1 eV = 1.602 x 10^{-19} J). The 26.9 MeV represents a theoretical upper bound of ~ 34x total input power.

As there are ~ 10^{14} of these 26.9 MeV energy releases taking place per second on the 1 cm^2 LENR device, the total energy release is 4.28 x 10^{-12} J/cm^2/sec x 10^{14} = 428 J/cm^2/sec. This represents 428 W/cm^2, a large power density. At a lesser ULM neutron production rate of 1 x 10^{12} cm^2/sec, the overall energy production rate would drop down to 4.28 J/cm^2/sec or 4.28 W/cm^2. At a ULM neutron production rate of 1 x 10^{11} cm^2/sec, the energy production rate would drop down to 0.428 J/cm^2/sec or 0.428 W/cm^2, which is close to levels of excess heat output that are often observed in the *limited subset* of electrolytic LENR experiments that researchers deem 'successful' at making excess heat.

In this example, an energy generating rate of 428 W/cm^2 means 0.428 kWh/cm^2 produced in an hour for a Lithium-6-fueled 1 cm^2 LENR device, without releasing any CO_2. In comparison to the minuscule total mass of LENR reactants, the complete combustion of 1 US gallon of gasoline (weighing 2.7 kg) generates ~33.56 kWh of heat energy and releases ~8.8 kg of CO_2 into the atmosphere.

Scaling up the surface area of the idealized LENR device 1,000 fold would give a 428 kW power source, while a 1 m^2 device would give a 4.28 MW power source.

According to WLT, experimentally observed 'excess heat' from condensed matter LENR devices should be closely correlated to their rates of ULM neutron production.

Concluding remark from our 2010 "*Primer*" paper about the possibility of commercializing LENRs:

"The analysis presented in this paper leads us to conclude that realistic possibilities exist for designing LENR devices capable of producing 'green energy', that is production of excess heat at low cost without lethal nuclear waste, dangerous gamma rays or unwanted neutrons. The necessary tools and the essential theoretical know-how to manufacture such devices appear to be well within the reach of presently available technology. Vigorous efforts must now be made to develop such devices whose functionality requires all three interactions of the Standard Model acting in concert."

"A primer for electroweak induced low-energy nuclear reactions"
Y. N. Srivastava, A. Widom, and L. Larsen
Pramana – Journal of Physics **75** (4) pp. 617 – 637 October 2010
http://www.ias.ac.in/pramana/v75/p617/fulltext.pdf

"Energy, broadly defined, has become the most important geostrategic and geoeconomic challenge of our time."

Thomas Friedman, *New York Times*, April 28, 2006