Green hard-radiation-free ultralow energy neutron reactions (LENRs) could provide game-changing nuclear power for military combat systems ranging from aircraft to individual warfighters

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“Unleash us from the tether of fuel.”

General James Mattis, former commander of the
1st Marine Division, during the drive to Baghdad, March 2003

Burning tanker trucks in NATO fuel convoy attacked by Taliban fighters (Pakistan, 2011)

Credit: AFP photo / Banaras Khan

2011: at that time some news sources claimed that as many as one in eight Army casualties had resulted from protecting fuel convoys

Ultralow energy neutron reactions (LENRs) are a new type of nuclear power technology that does not involve any fission or fusion - hot, cold, warm, or otherwise. Rather, application of appropriate input energy to specially engineered energetic nanomaterials can trigger reactions between quantum mechanically entangled electrons and protons (Hydrogen) in microscopic active sites that produce large numbers of benign subatomic particles called ultralow energy (ULE) neutrons and ghostly near-massless neutrinos. Now at TRL-4 (European Commission definitions), successful commercialization of LENRs offers a strategic opportunity to release U.S. military from Mattis' "tether of fuel."

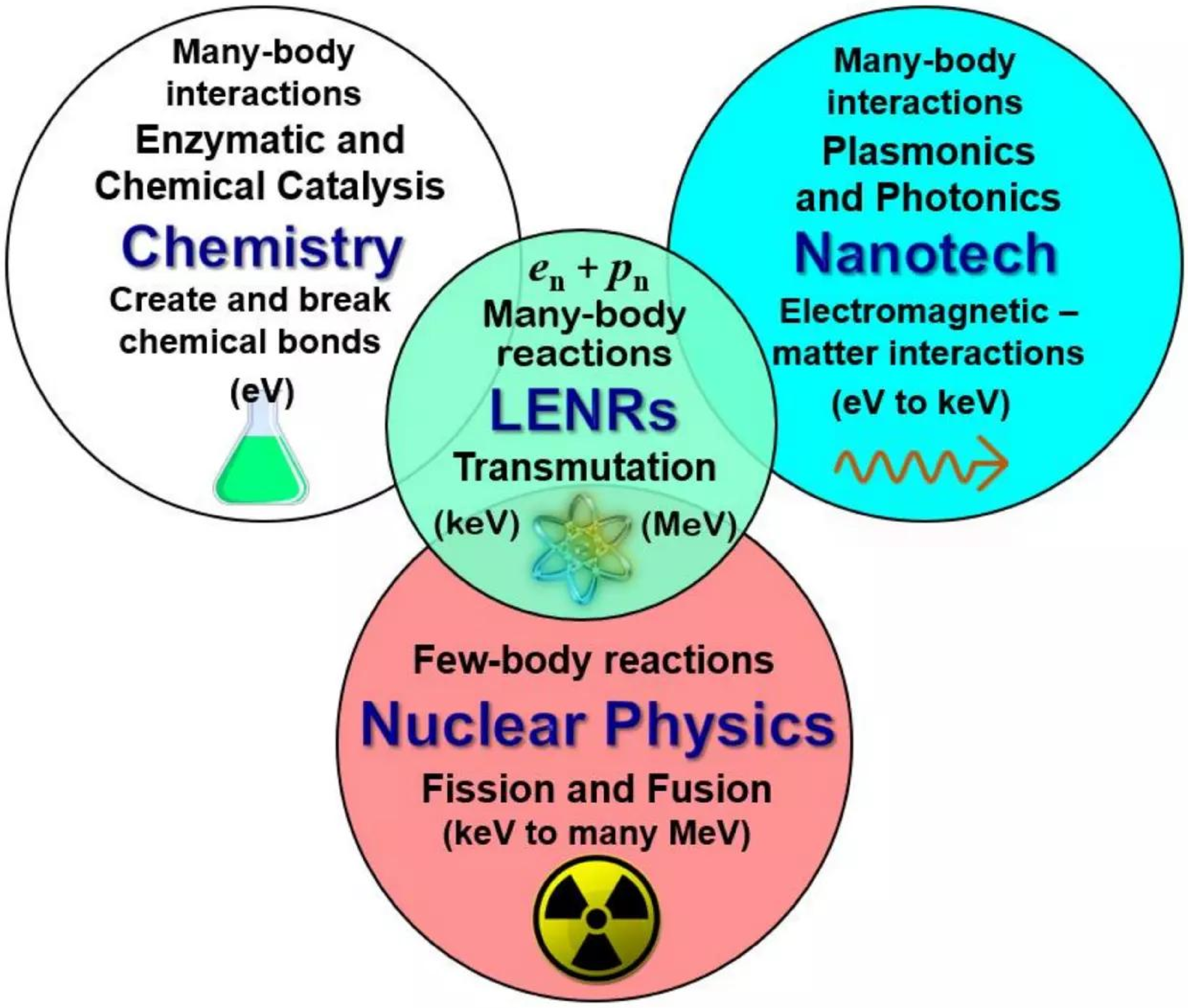
Three types of nuclear power: fission, fusion, and LENRs (new)

Heat producing nuclear process	Energetic MeV gamma γ radiation?	Energetic MeV neutron radiation?	Long-lived radioactive waste products?	Basic description of nuclear process which creates heat that can be harvested and converted	Scale of energy release (MeV) versus chemical (eVs)
Fission TRL 9^{+} Uranium^{235}	Yes	Yes	Yes	Unstable heavy nuclei capture neutrons and shatter into fragments	~ 200 MeV complex mix of end-products
Fusion TRL 4^{+} 2018 ITER D+T reactor in France 2025	Yes All fusion	Yes For D+T	No Induced	Gigantic temperatures enable light ionized nuclei to smash together and then fuse into heavier chemical elements	Depending on specific fusion reaction, value ranges from ~ 3 to ~ 24 MeV
LENRs TRL 4 In 2017 Japanese project had best-ever LENR heat production	No Heavy electrons convert γ into IR	No ~ All ULE neutrons captured locally	No Neutron-rich LENR products decay fast	Input energy creates ultra low energy neutrons (via $e + p$ reaction) that capture on target fuels. Gammas from neutron captures are converted into infrared; unstable products fast-decay into stable elements	Depending on fuels and subsequent reactions as well as decays, values range from ~ 0.1 MeV up to ~ 22 MeV

Credit: Lattice Energy LLC

While harmless neutrinos simply fly-off into space at near lightspeed, ULE neutrons are nearly all locally captured by target fuel nanoparticles deliberately emplaced near LENR active sites. Upon capture by target fuel atoms, ULE neutrons trigger release of stored nuclear binding energy from fuels as usable heat. Importantly, heavy-mass electrons also created in active sites will directly convert locally produced or incident gamma radiation into infrared (IR – heat). So although target fuels undergo ULE neutron-catalyzed nuclear transmutation, LENR active sites do not emit deadly energetic neutron or gamma radiation. Consequently, LENRs are a revolutionary hard-radiation-free source of nuclear power. All this is rigorously explained by peer-reviewed physics of Widom-Larsen theory of LENRs (*European Physical Journal C – Particles & Fields*, 2006 and *Pramana – Journal of Physics*, 2010). In fact, Widom-Larsen theory shows why LENRs are not really all that exotic; see following Venn diagram showing multidisciplinary interrelationships:

Green nuclear LENRs have deep connections to abiotic and enzymatic chemical catalysis, plasmonics, photonics, and nanotechnology

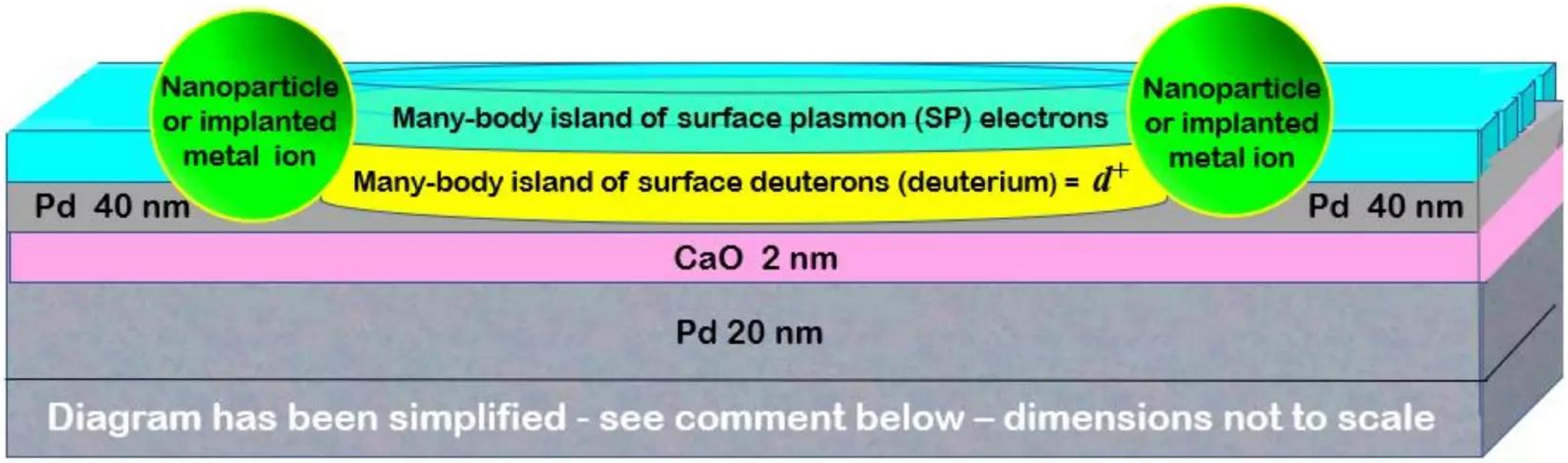


Credit: Lattice Energy LLC

Proprietary nanodevice engineering guidelines directly derived from details of Widom-Larsen theory (WLT) specify characteristics of local nanostructures needed to facilitate formation of ultrahigh transient local electric fields > 1.4 x 10^{11} V/m required for many-body collective ULE neutron production in LENR active sites. Altogether, this suggests future thermal device engineering progress could be accelerated by data mining from knowledge bases in chemical catalysis, plasmonics, and nanotechnology.

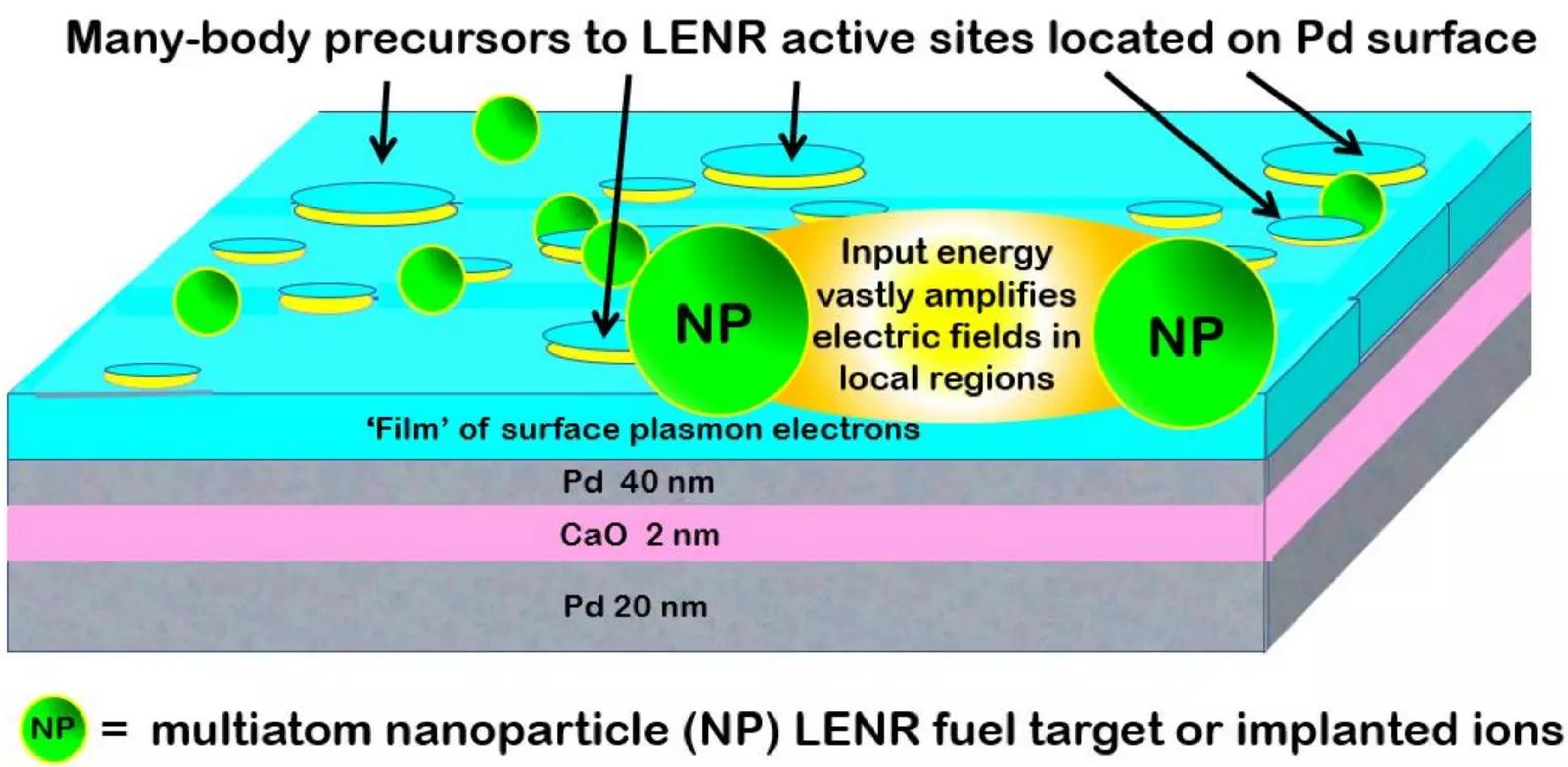
Per WLT, LENRs require input loading of Hydrogen to create many-body 'islands' of protons or deuterons (light and heavy Hydrogen isotopes) with dimensions of 2 nanometers to ~100 microns that are precursors to LENR active sites. Such islands form spontaneously on surfaces of fully loaded metallic hydrides and at interfaces: e.g. metal/air, metal/oxide, metal/H_2, etc. In metal hydrides, Hydrogen/metal atomic ratio in bulk metal hydride must be >0.80 for surficial islands to form. Loading can be accomplished with DC currents in H_2O/D_2O electrochemical cells or heating and high pressure in H_2/D_2 gas-loading reactors. Other types of loading methods can be utilized.

Conceptual overview of micron-scale precursor to a single many-body Widom-Larsen active site. Similar to earlier gas-loaded thin-film LENR devices fabricated by Mitsubishi Heavy Industries (Japan)



Credit: Lattice Energy LLC

Multiple inactive precursor sites and one active site (yellow) and many target fuel NPs. Input energy boosts local electric fields to >10^{11} V/m to create ULE neutrons



Credit: Lattice Energy LLC

Future multi-megawatt, fission-powered Mobile Nuclear Power Plants (MNPPs) could be excellent solutions for forward operating bases (FOBs) having large stationary power generation requirements. However, MNPPs would be vulnerable to precision attacks that would release large quantities of dangerous, highly radioactive fission products in the event of a core containment breach. Breach of LENR reactors would only release benign, non-radioactive fuel materials and very short-lived transmutation products.

Radiation-free LENR power generation and propulsion systems would not require heavy, expensive radiation shielding and containment systems for safe operation. Consequently, LENR-based systems could be vastly smaller and less expensive than any fission or fusion reactors. Unlike fission-based systems, lack of shielding requirements would allow unshielded LENR-based power sources to safely scale radically *downward* from large, multi-ton MNPPs. This would enable enormous expansion of safe ultra-high-energy-density nuclear power into a broad range of military applications including sensors, electronics, stationary & portable power, motor vehicles, ships, aircraft, and spacecraft.

Nuclear energy density vastly surpasses that of all chemical technologies

Fuel	Energy Type	Specific energy (MJ/kg)	Applications
Uranium (breeder) U-235 fission	Nuclear fission	80,620,000	Nuclear reactors: grid electric power generation plants and submarine propulsion
Thorium (breeder) Th-232 → U-233 fission	Nuclear fission	79,420,000	Thorium reactors under development for grid electric power generation plants
Electrons, protons (Hydrogen), and LENR target fuels such as Ni, Li, and aromatic Carbon	LENRs: neither fission nor fusion; transmutation of target fuels	Nickel target fuel est. ~3,817,235	Stationary, mobile, and portable power generation systems; electric power plants
Hydrogen (compressed to 70 MPa)	Chemical combustion	142	Rocket and automotive engines; grid storage and conversion
Diesel/Fuel oil	Chemical combustion	48	Automobile engines; certain types of power generation systems, e.g. diesel gensets
Jet Fuel	Chemical combustion	46	Aircraft
Gasoline (Petrol)	Chemical combustion	44.4	Automotive engines; other types of power generation systems
Best batteries today	Electrochemical	Barely > 1	Energy storage as electricity
Lithium-ion batteries	Electrochemical	0.4 – 0.9	Energy storage as electricity

Credit: Lattice Energy LLC

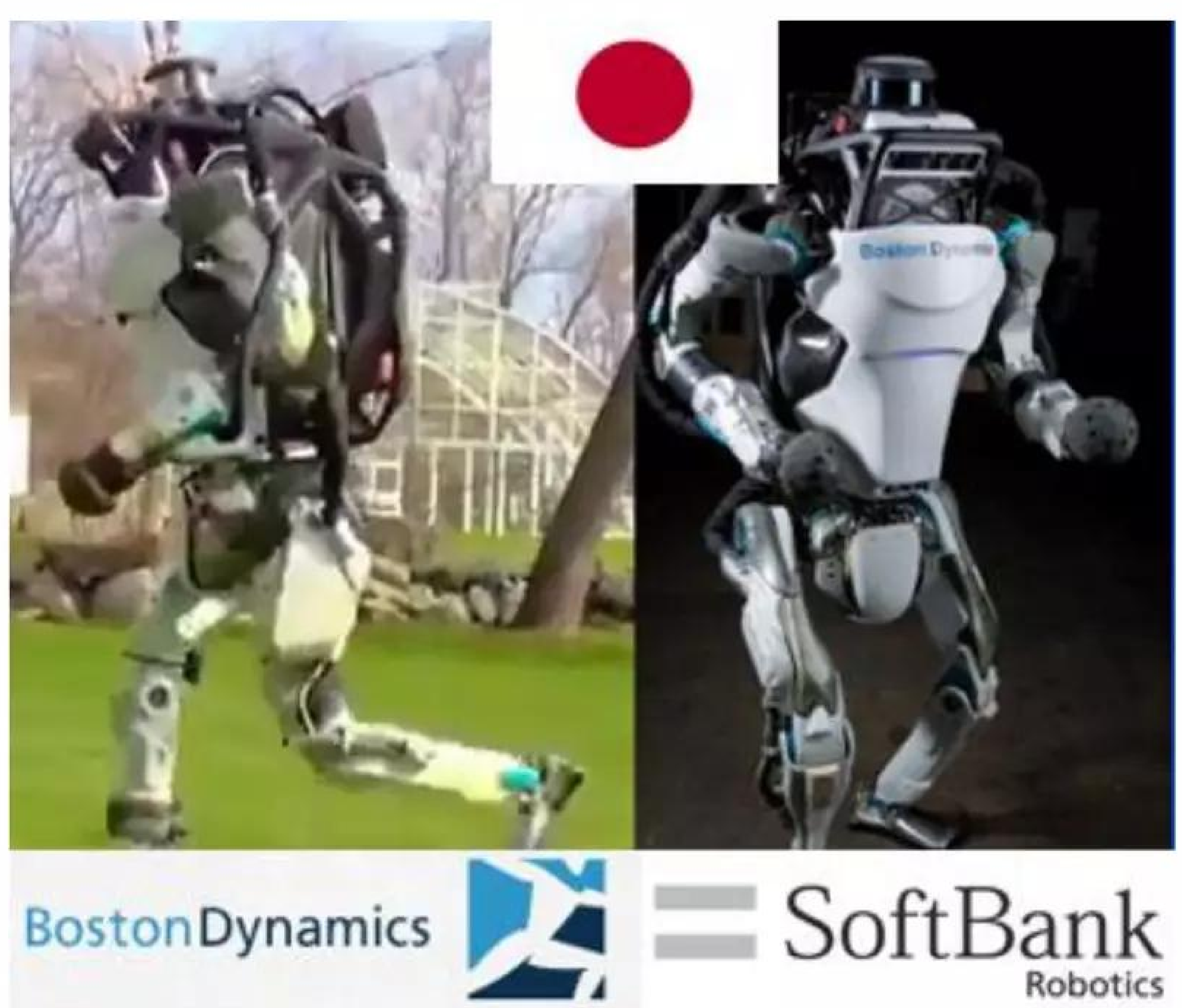
Absence of radiation shielding would enable development of battery-like portable LENR power sources that could drastically reduce typical 15 - 25 pound fighting or approach loads associated with a collection of chemical batteries now being carried by individual soldiers to power critical electronic systems during missions. Reduction in total carried weight could improve soldiers' speed of movement and reaction times, as well as cut resupply logistics 'tails', all of which contribute to increased combat effectiveness.

Typical collection of electronics and batteries used by U.S. airborne soldiers over 72-hour missions that occurred during Operation Enduring Freedom in Afghanistan

Credit: PEO Soldier Show

Energy density of present and future electrochemical batteries will never be high enough to enable militarily significant mission durations of at least 48 hours for autonomous robots and full exoskeletons.

Boston Dynamics Atlas robot's 3.7 kWh Li-ion onboard battery only lasts 1 hour



Credit: Boston Dynamics/SoftBank (Japan)

In 2017, Dmitry Semizorov, head of Russian state arms-design institute TsNIITochMash, announced they had developed a Titanium military exoskeleton. Unfortunately, there was one insoluble problem, no present electrochemical battery could provide adequate unrecharged operating lifetimes. Semyonov told *Newsweek*: “However, the matter of creating such a battery is not solved anywhere in the world. This is a shared problem.”

LENRs could enable development of compact, portable 3 - 15 kilowatt electrical power sources that could drive full exoskeletons, autonomous robots, and drones for unrefueled mission durations lasting several weeks.

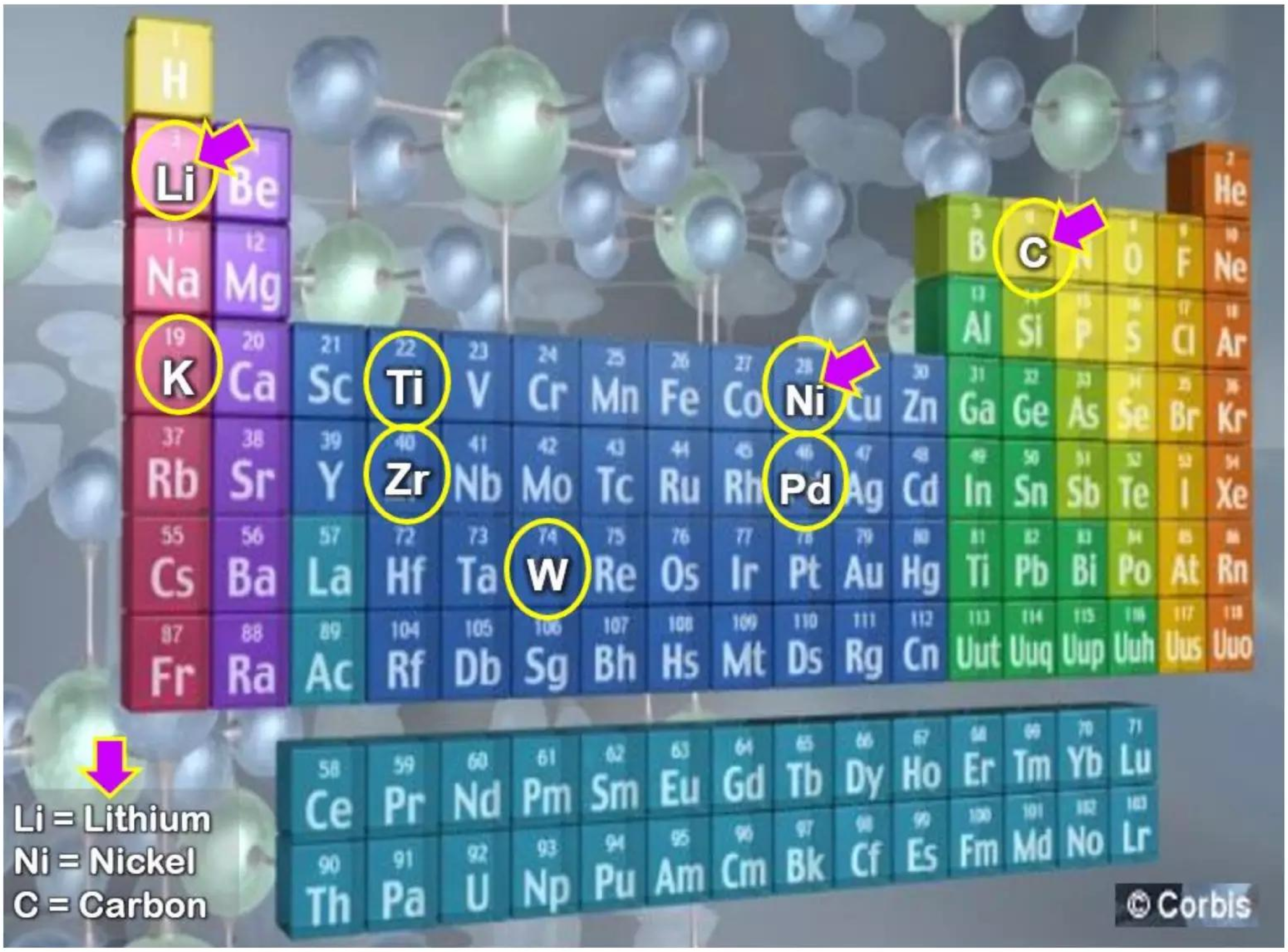
While there has been R&D on photovoltaic solar panel harvesters and knee/backpack frame kinetic harvesters to recharge soldiers’ batteries, these technologies are unlikely to produce enough extra power to decisively break-out of current limitations. LENRs are the only energy technology on the foreseeable horizon that could provide a quantum-leap in military power generation capabilities in the 2030 - 2050 time-frame.

Lockheed-Martin’s latest concept for a U.S. Army powered military exoskeleton

Credit: Lockheed-Martin

Any stable, non-radioactive element/isotope in Periodic Table of chemical elements that can capture ULE neutrons can serve as an LENR target fuel; some perform better and release more excess heat than others, e.g. Lithium (Li), Nickel (Ni), Titanium (Ti), and aromatic Carbon (C). LENR fuel transmutation processes typically proceed along rows of Periodic Table from left-to-right from target fuel starting points.

Examples of possible LENR target fuels shown in Periodic Table of chemical elements; Lithium, Nickel, and aromatic Carbon are attractive candidates



Credit: Corbis (Periodic Table of chemical elements)/annotated by Lattice Energy LLC

Energy densities of future commercial LENR fuels would be > 5,000x larger than gasoline; this unprecedented technological advantage would have very important military implications.

Major increases in ranges and mission durations of combat systems:

Automobiles, trucks, aircraft, or ships powered by LENRs could travel around the entire world on quantity of nanoparticulate fuel that would fit into a FedEx box. LENR fuels would be inert and benign and could safely utilize existing overnight package delivery systems and small drones for rapid resupply anywhere in the world.

Size of military fuel logistics pipelines would collapse dramatically:

Typical gasoline or diesel tanker trucks carry ~ 5,000 to 12,000 US Gallons of liquid fuel. LENR fuels producing same number of BTUs would fit into one large FedEx box. This revolutionary benefit of LENR nanoparticulate ‘green’ CO_2-free fuels is graphically illustrated on the next page.

LENRs: energy equivalent of a tanker full of gasoline could fit into FedEx box

Vulnerable military fuel convoys could become a thing of the past

Credit: Lattice Energy LLC

Aircraft propulsion systems based on use of LENR fuels would be game-changers. Enormous energy density of nanoparticulate LENR fuels would enable onboard fuel fractions required at vehicle takeoff to be slashed by 90% or more --- a revolutionary advance. High performance LENR-powered drones would have unrefueled mission durations and loiter times measured in weeks.

In 2015, Japanese government New Energy and Industrial Technology Development Organization (NEDO) organized and funded an LENR thermal device nanofabrication and testing project managed by Technova, Inc. Participants: Mitsubishi Heavy Industries, Toyota, and Nissan Motors; universities were Tohoku, Nagoya, Kobe, and Kyushu. Directly applying state-of-the-art nanotech and implicitly guided by Widom-Larsen theory, corporate and academic scientists working on NEDO's project have made major progress toward decisively overcoming intractable experimental problems that had previously been encountered in developing LENRs.

NEDO project researchers increased typical LENR device excess heat production from long-typical milliwatts for a few days to an average of ~5 Watts for as long as 45 days. This advance represents 1,000x better thermal performance versus all prior best-practices results. Repeatability of excess heat production increased from under 10 - 20% beforehand to an average >70 - 80%. These achievements advanced LENR technology readiness from TRL-3 to TRL-4 in ~3 years at cost of < US$54 million. Japanese researchers recently published Ragone Plot claiming specific energy of some of their LENR nanodevices is already >1,000x gasoline.

While Lattice spearheaded breakthrough development of many-body collective LENR physics and nanoparticulate device engineering, experimental leaders in production of excess heat with LENR devices are presently located in Japan. U.S. experimentalists are now probably at least 5 years behind NEDO researchers. Besides having inferior heat results compared to Japan's NEDO project, many U.S. LENR researchers still espouse long-discredited "D+D cold fusion" nonsense.

Further nanotech engineering is necessary to advance from NEDO project's crude TRL-4 laboratory protype reactors to TRL-9 commercial LENR thermal power generation systems. Technologists must achieve high-volume/low-cost fabrication of rationally designed nanostructures hosting large numbers of LENR active site precursors. These nanostructures must then be emplaced on working surfaces of LENR reactors in close proximity to target fuels such as Lithium, Nickel, aromatic Carbon (Benzene), etc.

Once cost-effective, high-yield device fabrication, triggering, and extended longevity are attained, total output of LENR reactors can be scaled-up via: (1) increasing designed area-densities of precursors to LENR active sites on fabricated nanostructures; and/or (2) injecting larger quantities of target fuel nanoparticles hosting precursors into larger-volume reaction chambers containing Hydrogen gas. Off-the-shelf energy conversion subsystems suited for particular applications can be selected and integrated with commercial LENR heat sources to create standalone power generation systems.

Over 26 years prior to NEDO's LENR nanofabrication and device testing project in 2015, total cumulative worldwide R&D spent on LENRs was probably ~US$250 million; LENRs nevertheless advanced from TRL-1 to TRL-3. Including NEDO project, cumulative global funding of LENR R&D since 1989 was < US$ 300 million.

Number of researchers working full-time on LENR R&D now totals <200 worldwide. Since LENRs are at TRL-4 and could advance rapidly to TRL-9 with aggressive funding, major increases global R&D spending are warranted. It is now time for U.S. government and private sector to accelerate LENRs' pace of development before potential near-parity military rivals like China or Russia get there first.

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Please also see White Paper and peer-reviewed publications on W-L theory:

Lattice White Paper, May 16, 2019: "LENRs enable radiation-free green nuclear power and propulsion" https://www.slideshare.net/lewisglarsen/lattice-energy-llc-lenrs-enable-green-radiationfree-nuclear-power-and-propulsion-may-16-2019

"Ultralow momentum neutron catalyzed nuclear reactions on metallic hydride surfaces" A. Widom and L. Larsen *European Physical Journal C - Particles and Fields* **46** pp. 107 - 112 (2006) http://www.slideshare.net/lewisglarsen/widom-and-larsen-ulm-neutron-catalyzed-lenrs-on-metallic-hydride-surfacesepjc-march-2006

"A primer for electro-weak induced low energy nuclear reactions" Y. Srivastava, A. Widom, and L. Larsen *Pramana - Journal of Physics* **75** pp. 617 - 637 (2010) http://www.slideshare.net/lewisglarsen/srivastava-widom-and-larsenprimer-for-electroweak-induced-low-energy-nuclear-reactionspramana-oct-2010

