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Commercializing a next-generation source of safe CO_2-free nuclear energy

Game-changing low energy neutron reactions (LENRs)

What are they and what amazing things could they enable?

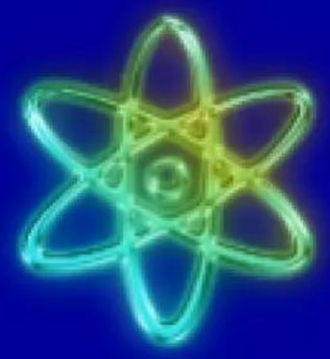
Overlooked by scientists for >100 years because deadly hard radiation is absent

1940s

2005: development of Widom-Larsen theory of LENRs enables transition

2014 and beyond

Evolution of nuclear technology



Today's fission and fusion were born in 1940s weapons programs

Radiation-free LENRs were overlooked from early 1900s

August 6, 2014

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http://www.slideshare.net/lewisglarsen/presentations

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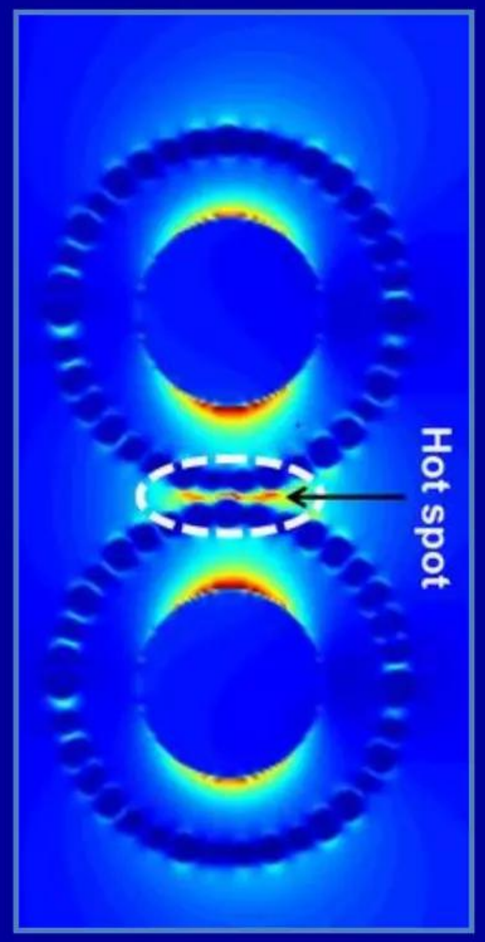
Commercialization of LENR technology could:

Create a new era for portable, stationary, and mobile power generation

- ✓ Lacking production of deadly radiation or hazardous long-lived radioactive wastes, LENR power systems would not require any expensive and massive shielding, containment, or waste clean-up
- ✓ Coupled with intrinsic multiway scalability, these unique attributes would enable development of highly competitive commercial products with outputs ranging from milliwatt to megawatts suitable for portable, stationary, vehicular, and aerospace power markets
- ✓ Portable LENR power sources could vastly exceed the overall performance capabilities of advanced chemical batteries and fuel cells with regard to system energy density and operating longevity
- ✓ End-user price per BTU or kWh for LENR-based power systems could be substantially lower than prices for competing batteries or fuel cells, combustion, and present fission and fusion technologies

Fig. 7 – E-field hot spots between neighboring nanostructures



S. Kochuveedu *et al.*, *Scientific Reports* (*Nature*) 4 Article number: 4735 (2014)

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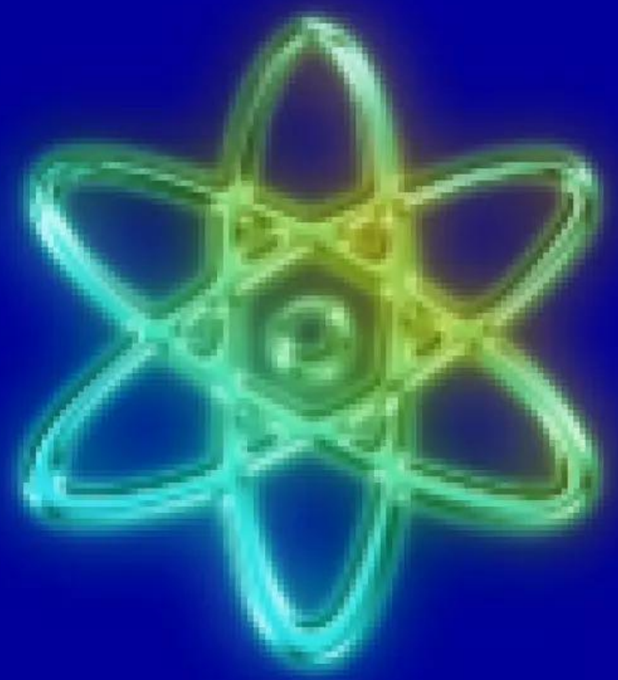
What are low energy neutron reactions or LENRs?

New nuclear energy source that does not involve any fission or fusion

- ✓ LENRs would be much safer than today's fission and hoped-for future fusion nuclear power generation technologies because they do not emit any deadly high-energy gamma or energetic neutron radiation
- ✓ LENRs also do not produce any environmentally hazardous, long-lived 'hot' radioactive wastes
- ✓ LENR-based power systems would not require any heavy, expensive radiation shielding and related containment subsystems nor would there be costly waste clean-up for spent fuel and old reactors
- ✓ Rather than fission or fusion which are few-body strong interaction processes, key features of LENRs involve many-body collective electroweak reactions



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Widom-Larsen theory explains LENRs' green attributes

It also explains 100 years of experimental data that was inexplicable

Absorption of neutrons triggers release of nuclear binding energy from atoms

- ✓ Widom-Larsen theory explains all LENRs' green characteristics, has been published in respected peer-reviewed physics journals, and explains 100 years of anomalous published experimental data
- ✓ Scientists have been reporting various LENR effects in experiments since ~1900 but didn't attribute them to nuclear processes due to an absence of radiation
- ✓ "Electroweak" reactions are simple: heavy-mass electron e^{-}*reacts directly with a proton p^{+} (hydrogen nucleus) to create neutron n^{0} plus a benign neutrino ν_e
- ✓ Safe ultra-low energy neutrons are potent nuclear 'matches' that can trigger release of stored nuclear binding energy when absorbed by nearby 'fuel' atoms

Neutrons are akin to matches

$$e^{-}*_{sp} + p^{+} \rightarrow n^{0} + \nu_e$$

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Abbreviated historical chronology of LENRs since 1900

1925: Nagaoka made Gold and Platinum with intense electric discharges

1900 - 1928: Many top scientists in Europe published refereed reports of nuclear transmutation and production of elements observed spectroscopically during high-current electric arc discharges in gases; theory not understood even though data was very solid

1922: University of Chicago chemists Wendt & Irion published paper in *Science* claiming to have spectroscopically detected Helium production in evacuated glass 'bulbs' wherein a Tungsten wire was exploded with high-current electric pulse; work attacked by Rutherford in *Nature*; Wendt answered his criticisms correctly but was not believed - he discontinued work on exploding wires

1925: Most famous physicist in Japan at that time, Hantaro Nagaoka, produced Gold and/or Platinum in >200 experiments involving electric arcs between Tungsten electrodes totally immersed in transformer oil; published a report in *Nature* and distributed specimens of his produced Gold around the world but was still not believed by majority of scientists and discontinued the work

Hantaro Nagaoka

1925

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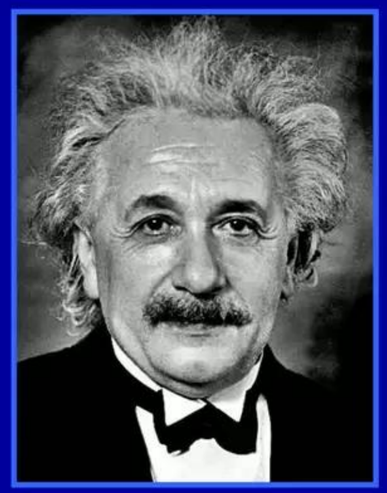
Abbreviated historical chronology of LENRs since 1900

1951: Einstein thought neutrons could be made via collective Q-M effects

1951: Aspiring PhD student at Cornell named Sternglass conducted experiments with a Hydrogen-filled X-ray tube in which he clearly observed neutrons being produced by an apparent electroweak $e + p$ reaction at anomalously low 30 keV voltages. No one at Cornell including Bethe and Feynman understood why these experiments had worked. After examining data, Einstein thought it might be explained via many-body collective quantum effects with electrons; inexplicably wishing to avoid provoking a major controversy, Sternglass stopped this work; never published it

Albert Einstein



1951

1989: Two University of Utah electrochemists, Pons & Fleischmann, published a paper claiming to have observed production of anomalous amounts of heat and Helium-4 in simple heavy-water D_2O electrolytic cells - explained results by postulating a D+D "cold fusion" reaction; not believed and ultimately discredited

2006: Widom & Larsen published theory of LENRs in the *European Physical Journal C - Particles and Fields* - explains 100 years of above-noted data with many-body collective quantum E-D effects

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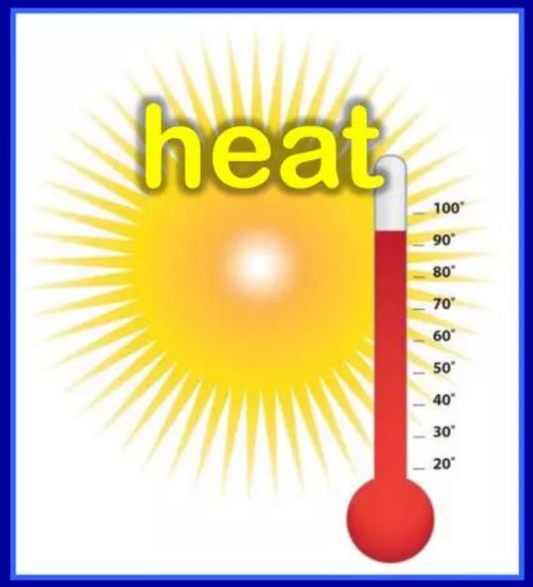
Catalytic low energy neutrons trigger heat production

Release of nuclear binding energy creates vast amounts of usable heat

Neutrons + target fuel atoms ⟶ heavier elements + decay products

capture +

on target fuel atoms produces →



Neutron 'match'

Neutrons readily absorbed by LENR fuel targets such as inexpensive Nickel, Titanium, Lithium, or Carbon

Direct conversion of neutron capture and decay-related gammas to IR and beta/alpha particles create heat

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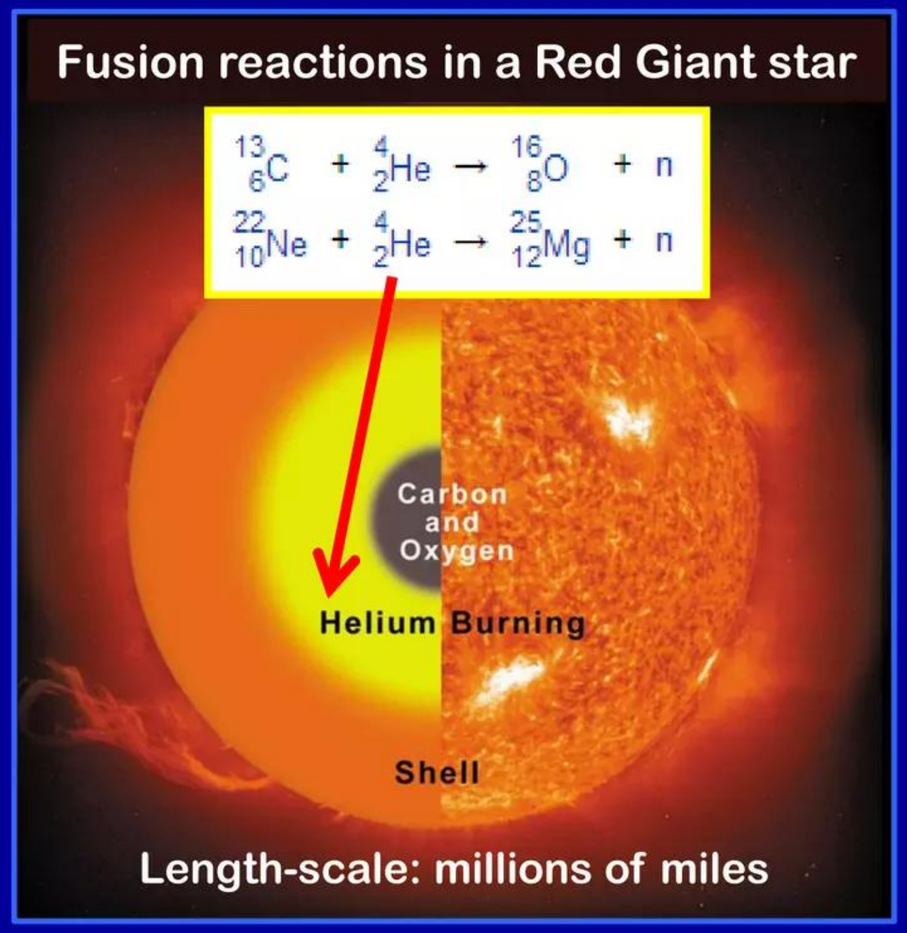
Physically gigantic nuclear reactors are unnecessary

LENRs utilize many-body collective $e + p$ reaction to make neutrons

Such neutrons have low energy, are captured locally, and do not escape reactors

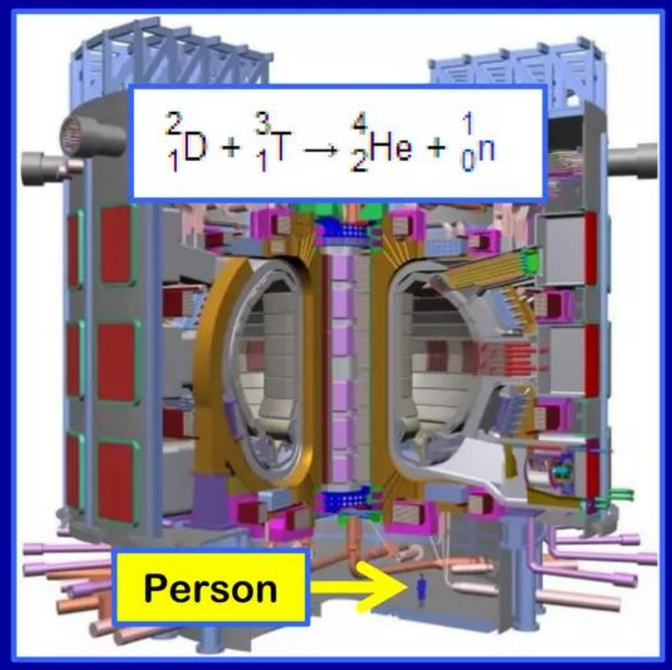
Fusion and LENR 'weak' nuclear reactions shown in diagrams all produce neutrons (n):



Temperatures: millions of degrees

Dangerous energetic 14.1 MeV neutrons

ITER: D+T fusion reactor (France)

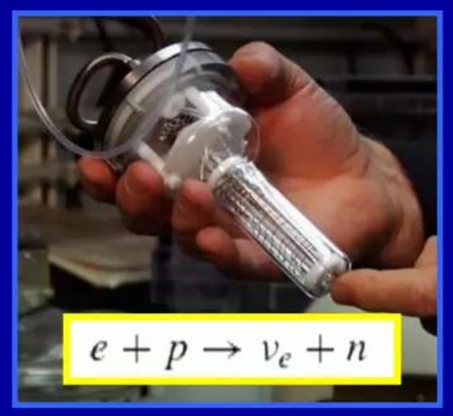


Length-scale: hundreds of feet

Temperatures: millions of degrees

These are safe

LENR device



Length-scale: inches

Temperatures: thousands of degrees in microscopic regions

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LENRs dramatically shrink size of nuclear power plants

Huge flexibility in system scalability when radiation/waste are not issues

Fission reactors need 1 foot of steel and 3 feet of concrete to protect humans from hard radiation and wastes emitted by reactor; makes systems intrinsically large and heavy

LENRs enable small, portable battery-like power source devices that are safe to operate and disposable in landfills

Present-day fission reactor in California, USA

LENR power plants can range from very large to very small

Evolution of nuclear technology

Much larger LENR devices based on dusty plasma embodiments can potentially scale-up to megawatts; akin to today's power plants

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Nuclear energy density dwarfs chemical power sources

Achievable LENR system energy densities likely to be >5,000x chemical

LENRs Versus Chemical Energy Sources: Batteries, Fuel Cells, and Microgenerators	
Source of Energy	**Approximate Energy Density (Watt*hours/kg)**
Alkaline Battery	**164**
Lithium Battery	**329**
Zinc-Air Battery	**460**
Direct Methanol Fuel Cell (35% efficient)	**1,680**
Gas Burning Microgenerator (20% efficient)	**2,300**
100% Efficient Combustion of Pure Methanol	**5,930**
100% Efficient Combustion of Pure Gasoline	**11,500**
LENRs (based on an assumption of an average of 0.5 MeV per nuclear reaction in an LENR system)	**57,500,000** (maximum theoretical energy density – only a fraction would be achievable in practice)

Chemical Energy Sources

LENRs

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Dramatic illustration of huge LENR energy densities

LENR fuels for SR-71 mission could likely fit in just two FedEx boxes

SR-71 Blackbird carried ~12,000 gallons of JP-7 aviation fuel with full tanks; permitted unrefueled range of about 3,250 miles traveling at Mach 3.0

Large or fast aircraft require megawatt power outputs

Mass of fuel carried collapses

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LENR dusty plasma systems should scale-up to MW

Lattice scramjet concept outlines a possibility for large power sources

- ✓ LENRs can be triggered on target fuel nanoparticles injected into dusty plasmas; should readily scale-up volumetrically to megawatt (MW) total thermal outputs
- ✓ Concept as applied to a scramjet engine is outlined in 6/13/2014 Lattice document: http://tinyurl.com/kubdjc9
- ✓ LENR thermal sources could likely produce neutron fluxes of 1 x 10^{14} cm^2/sec that can then create thermal power fluxes of ~428 W/cm^2 using Lithium target fuel
- ✓ Total thermal fluxes created at focus receivers of concentrated solar power (CSP - see right) systems can reach values on the order of roughly 200 - 400 W/cm^2; this ~ matches LENR heat fluxes noted above
- ✓ Could potentially adapt Brayton cycle CSP systems for use in large LENR-based dusty plasma reactors

Dish CSP system

Tower CSP system

Ivanpah - California, USA

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LENRs could power Rankine and Brayton cycle engines

Brayton cycle LENR-based power systems could readily be 30% efficient

- ✓ Limitations on macroscopic working temperatures in LENR systems would be determined by thermal tolerances of materials used in a system; to the degree components withstand intense heat, LENRs could provide whatever temperatures are necessary to satisfy application-specific requirements
- ✓ Google investigated development of Brayton cycle for CSP systems because a Brayton does not require any water to produce power or for cooling (air in, air out) and design could scale up to 1 megawatt; Google estimated Brayton engine efficiency all by itself at 37% and entire integrated system efficiency at ~30%
- ✓ This opens up a possibility to develop potent combined cycle LENR dusty plasma-based power systems that can be scaled-up from a few kilowatts to tens of megawatts; such systems might achieve up to 50 - 60% overall efficiency
- ✓ When no chemical combustion is present, external venting of exhaust gases is unnecessary; thus LENR-based Brayton-cycle-only power systems could safely be used indoors to do combined heat and power (CHP) and achieve application efficiencies inside building structures that could effectively approach 80 - 90%

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Modular 30 kW (thermal) LENR systems ideal for homes

Distributed generation works well in urban as well as remote rural areas

- ✓ Small steam turbines (see to the right) have been developed that would be ideal for use in homes; could be integrated with boilers heated by LENRs
- ✓ Enough LENR fuel for a year of operation could probably be shipped overnight in large FedEx box
- ✓ If a 30 kW LENR thermal source were integrated with heat-to-electricity energy conversion system that was only 20% efficient, home power system could produce ~6 kWh electrical and 24 kW heat; satisfy energy demand for 95+% of homes in world
- ✓ Distributed generation helps to stabilize existing urban grids; also enables very cost-effective global rural electrification for presently powerless people

Green Turbine™ steam generator
1.2 to 15 kWh

See: http://www.greenturbine.eu/GT15.html

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What is amazing consequence of being radiation-free?

Absence of any deadly radiation enables portable nuclear power sources

- ✓ Lack of radiation enables development of quite long-lived, lightweight, very compact LENR power sources
- ✓ Systems would consist of LENR thermal sources integrated with various heat-to-electricity conversion subsystems and associated control electronics
- ✓ Examples of useful off-the-shelf energy conversion technologies include solid-state thermoelectric devices, tiny MEMS Rankine steam engines, etc.
- ✓ LENR manufacturing costs may be ~comparable to advanced batteries that use nanotech fab techniques
- ✓ **Future commercial versions of portable battery-like LENR power sources could then compete directly with advanced types of chemical batteries and fuel cells**

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Lattice estimates improvements in product performance

Dramatic increases in range with as little as 10x greater energy density

	Product Name	Present capabilities with today's power sources Range (endurance)	Vastly enhanced capabilities with future LENR-based power sources	
			10x chemical	100x chemical
Various aircraft	Yuneec e-430	150 miles (2.5 hours)	1,500 (25)	15,000 (250)
	Airbus E-Fan 2.0	99 miles (1 hour)	990 (10)	9,900 (100)
	Predator MQ-1	1,800 miles (24 hours)	18,000 (240)	180,000 (2,400)
	Super Heron	est. ~4,000 miles (45+ hours?)	40,000 (450+)	400,000 (4,500)
	Springtail	184 miles @ 94 mph (2.2+ hours)	1,840 (200+)	18,400 (2,000+)
	Crazyflie	Speed not measured (3 - 10 minutes)	? (30 - 100 min.)	? (maybe 5 - 17 hrs.)
	InstantEye	est. ~8 miles @ 25 mph (18 - 20 min.)	est. 80 (3.2 hrs.)	800 (32 hrs.)
	Tesla Model S car	~300 miles (4 - 5 hours @ 70 mph)	3,000 (40 - 50)	30,000 (400 - 500)
	Exoskeletons and autonomous robots	Require tether cables connected to external power sources	Duration of autonomous activity could be extended to weeks or even months	

Note: ~ 730 hours in month and 8,760 hours in a year; average IC car engine in U.S. runs for ~5,000 hrs over lifetime

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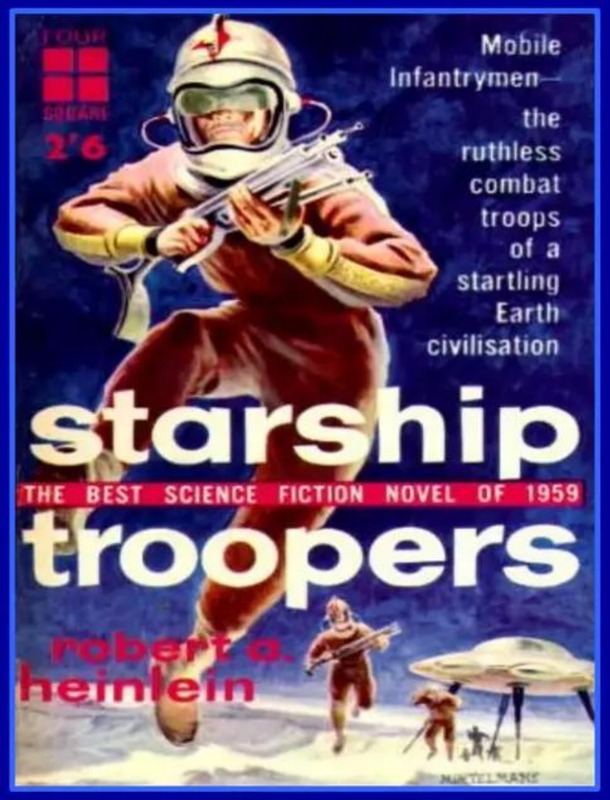
LENRs could power military or civilian exoskeletons

Sometimes life imitates art: late 1950's science fiction becomes reality

Technological dream is to deploy autonomous *Starship Troopers* "power suits"

Science fiction novel 55 years ago



"Starship Troopers" by R. A. Heinlein
G.P. Putnam (1959)
origin of "power suits"

U.S. Army TALOS *ca.* 2013

U.S. Army 2014 and beyond

See President Obama on CNN announcing U.S. Army's "Iron Man": http://www.youtube.com/watch?v=77pnVFLkUjM/

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Who is working to commercialize LENRs besides Lattice?

Major Japanese companies are doing R&D and filing patents on LENRs

- ✓ Number of major Japanese companies that include Mitsubishi Heavy Industries and the Toyota Group (among others) are working very quietly without any public fanfare to commercialize LENR technology; is ostensibly pursued for nuclear waste remediation --- this is not plausible for Toyota
- ✓ *Au contraire*, these R&D programs really aim to create a radical new type of radiation-free, primary energy source safe-enough to someday replace burning of petrol in internal combustion engines and supplant advanced batteries or fuel cells in high-performance portable/mobile power applications
- ✓ Oct. 2013: Toyota published paper in *Japanese Journal of Applied Physics* that confirmed earlier Mitsubishi work which had claimed to transmute Cesium targets into Praseodymium via forced diffusion of Deuterium gas through thin-film Pd metal-oxide heterostructures at modest temps and pressures

MITSUBISHI HEAVY INDUSTRIES, LTD.

TOYOTA

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What organizations are studying LENR applications?

Feb. 25, 2014: LENR Aircraft - NARI Seedling Seminar (Doug Wells)

Background

LENR is a type of nuclear energy and is expected to be clean, safe, portable, scalable, and abundant. The expected benefits make it an ideal energy solution. When it is applied to aircraft, LENR removes the environmental impacts of fuel burn and emission from combustion. Excess energy can be used to reduce noise so that all three of NASA's technology goals for future subsonic vehicles are either eliminated or addressed. Furthermore, aviation impacts almost every part of our daily lives, civilian and military. A revolutionary technology like LENR has the potential to completely change how businesses, military, and the country operate as a whole, giving a tremendous financial, tactical, and resource advantage to the country that utilizes it in the most effective way.

LENR creates some unique capabilities as well as challenges for integration into aircraft. The LENR concept that has reported most of the success generates heat in a catalyst process that combines nickel metal (Ni) with hydrogen gas (H). The initial testing and theory show that radiation and radioisotopes are extremely short lived and can be easily shielded. Although nuclear fission has been looked at for use in aircraft, LENR is different. LENR has a higher energy density and no radioactive by products.

Success of this research will provide a firm foundation for future research and investment for LENR technology integration into aircraft. Key research and development areas will be identified with any gaps in the current technology research. This research will guide NASA on the most effective way to invest in LENR to be the world leader in LENR aircraft research.

Source: http://nari.arc.nasa.gov/sites/default/files/attachments/17WELLS_ABSTRACT.pdf

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What organizations are studying LENR applications?

NASA and Boeing: NASA/CR-2012-217556 - subsonic ultra green aircraft

Subsonic Ultra Green Aircraft Research
Phase II: N+4 Advanced Concept Development

Quoting directly from Page #83 in this 2012 contract report:

"Technology Status: Multiple coherent theories that explain LENR exist which use the standard Quantum Electrodynamics & Quantum Chromodynamics model. The Widom-Larson (10) theory appears to have the best current understanding …"

Screen-capture image excerpt taken from Page #120 in this 2012 report:

Unducted fans, fuel cells, and BLI are potential enhancing technologies that offer significant improvements.

LENR technology is potentially game-changing to not just aviation, but the worldwide energy mix as well. This technology should be followed to determine feasibility and potential performance.

Hydrogen technology also has potential benefits, but widespread aviation use of hydrogen

See: http://www.slideshare.net/lewisglarsen/lattice-energy-llc-report-reveals-boeing-and-nasa-investigating-lenrpowered-aircraftaug-3-2012

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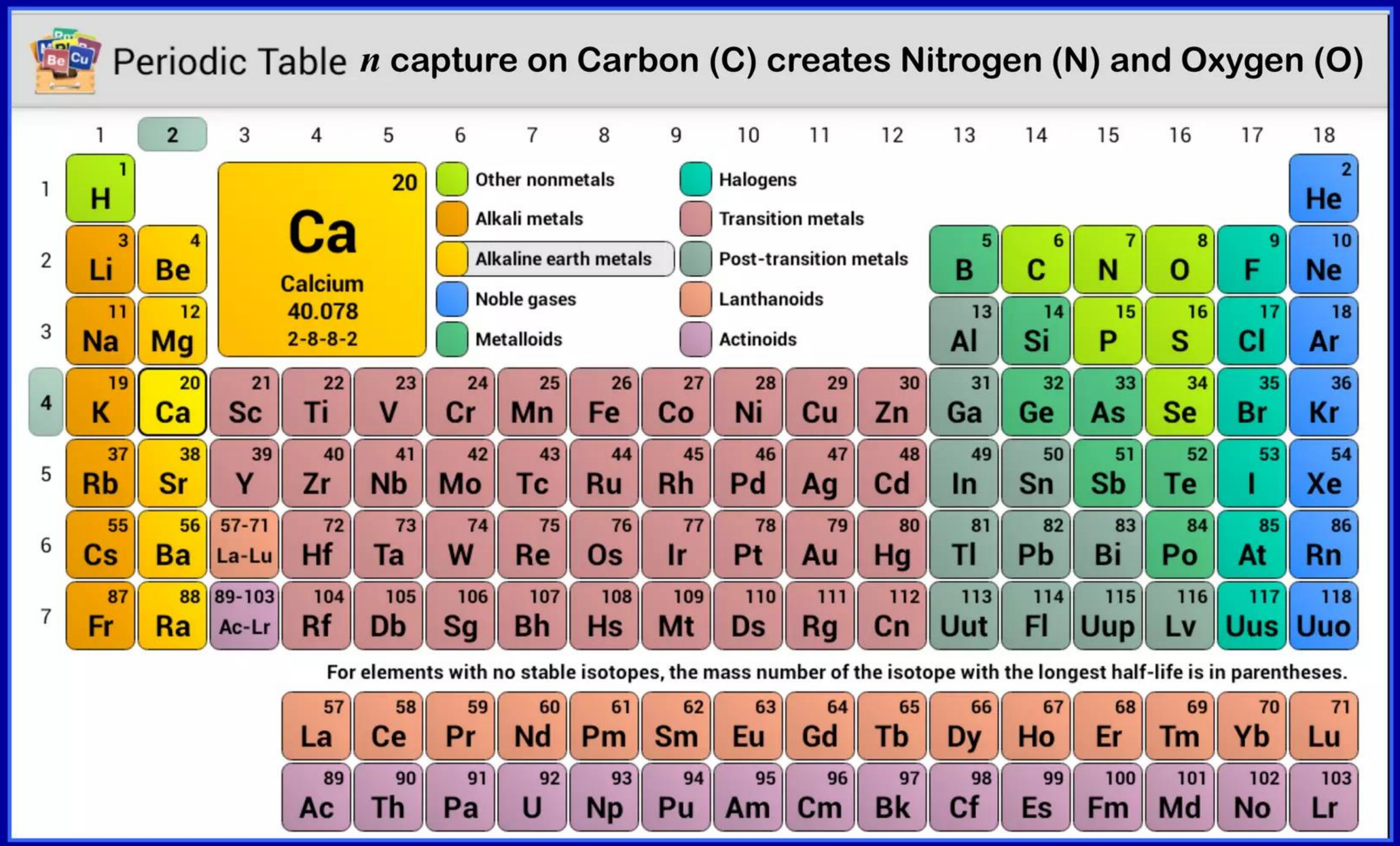
LENRs can make any element listed in Periodic Table

Neutron captures/beta decays drive process from left-to-right along rows



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Incredible variety of LENR fuels for many applications

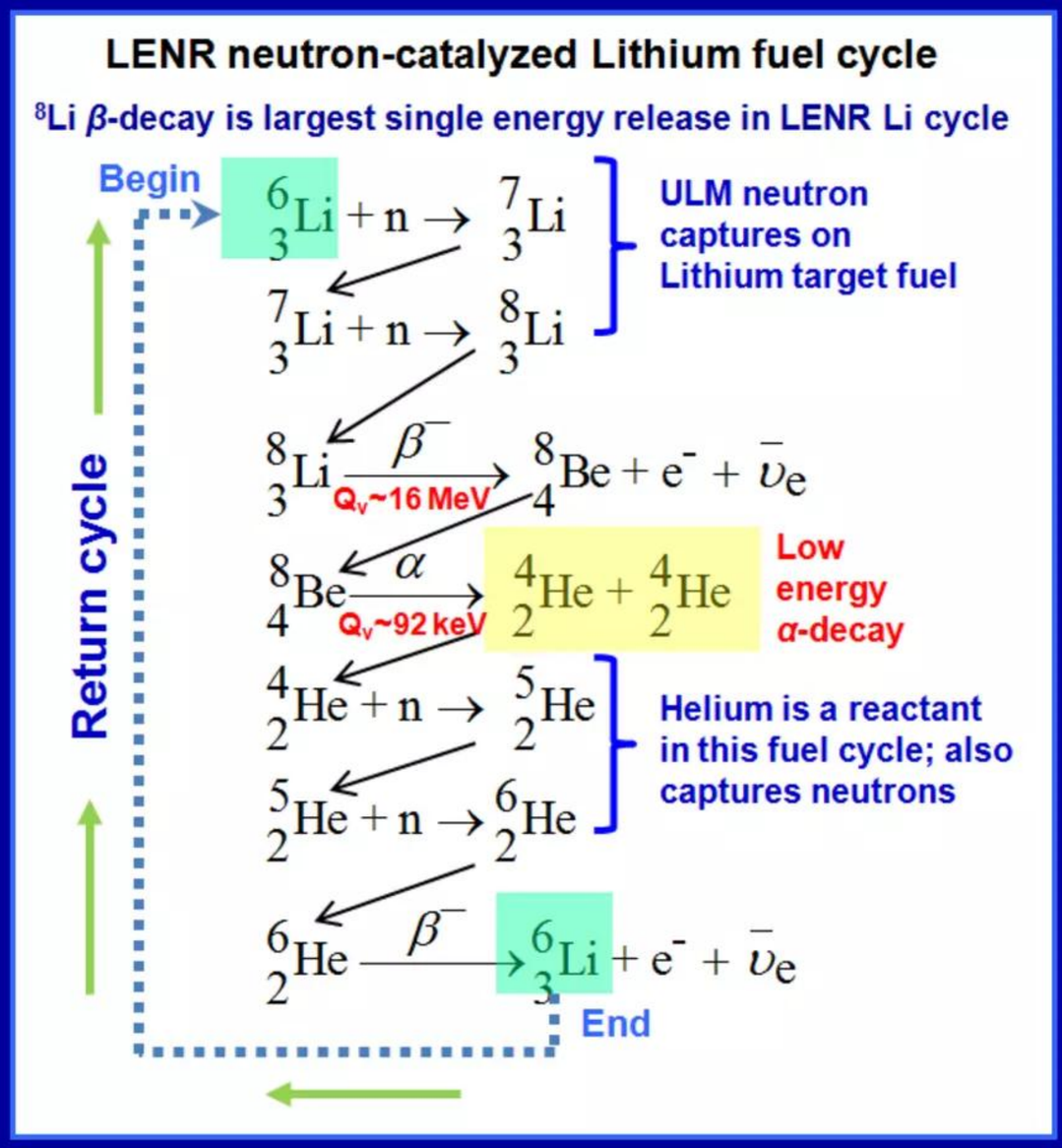
Lithium fuel cycle releases more energy than ITER's D-T fusion reaction

- ✓ Widom & Larsen's *European Physical Journal C* paper (2006) shows following LENR target fuel cycle using ordinary Lithium:

  Lithium-6 + 2 ULM neutrons → 2 Helium-4 + beta particle + 2 benign neutrinos + Q-value = 26.9 MeV

- ✓ Deuterium-Tritium (D-T) fusion reaction Q-value = 17.6 MeV creates dangerous high-energy neutrons

- ✓ LENR Lithium fuel releases larger amounts of energy and does not produce *any* deadly hard radiation



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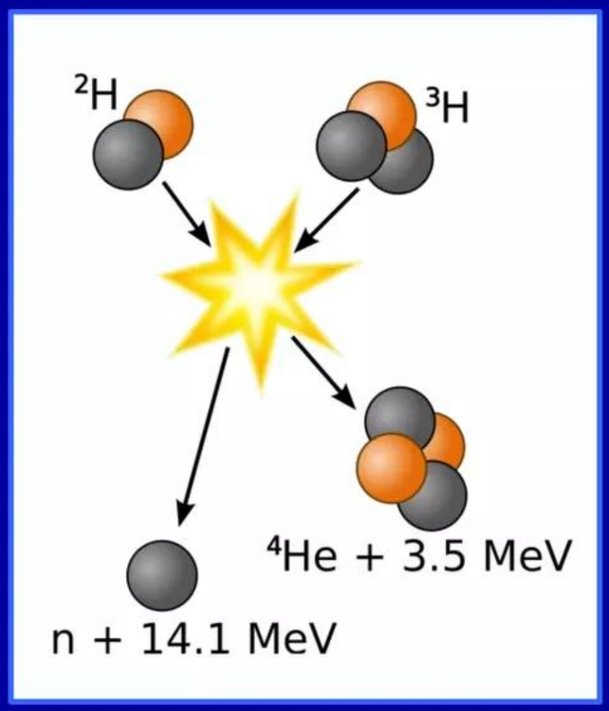
LENRs compare very favorably to fusion technology

ITER (France) uses D-T and Tri Alpha Energy (US) uses p^+ + ^{11}B reaction

- ✓ D-T fusion reaction releases 17.6 MeV, mostly in form of very hard-to-manage 14.1 MeV neutrons
- ✓ Tri Alpha's "aneutronic" fusion reaction between a charged proton (p^+) and Boron-11 atomic nucleus does not produce any neutrons, Q-value = 8.7 MeV, and is written as: $^1p^+ + {}^{11}B \rightarrow 3\ {}^4He$ (alpha particles)
- ✓ Radiation-free LENR Lithium fuel releases ~27 MeV
- ✓ All nuclear fusion reactions including Tri Alpha's have a reaction cross-section of at least 1 x 10^{-5} to produce deadly, hard-to-shield gammas >>> 10MeV
- ✓ Per Widom-Larsen, unreacted heavy electrons in LENR-active sites automatically convert gammas from ~0.5 up to ~11 MeV into benign infrared heat

D-T fusion reaction



Simple LENR neutron capture on Nitrogen releases 10.8 MeV; see diagram on Slide #29

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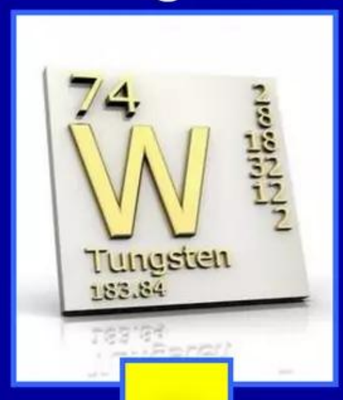
Modern nuclear alchemy realizes an age-old dream

Neutron-catalyzed LENRs can transmute Tungsten base metal into Gold

- ✓ In varied philosophical traditions which were once pursued all over the world, for nearly ~4,000 years large throngs of enthusiastic alchemists (that even included Isaac Newton) unsuccessfully pursued the goal of transmuting elements
- ✓ Modern alchemy - that is, neutron-catalyzed transmutation of base metals based on contemporary nuclear science --- really began in 1941 when Sherr *et al.* produced unstable Gold isotopes from Mercury using fission reactor neutrons
- ✓ Widom-Larsen theory (WLT) predicts that stable Gold can be created by ultra-low-energy LENR neutron captures on Tungsten (see next slide). This key pathway was actually observed experimentally in 1925 by Hantaro Nagaoka in Japan (who was not believed at the time); it was recently confirmed by Mitsubishi Heavy Industries who reported data consistent with WLT pathway at ANS meeting in 2012

Tungsten



Gold

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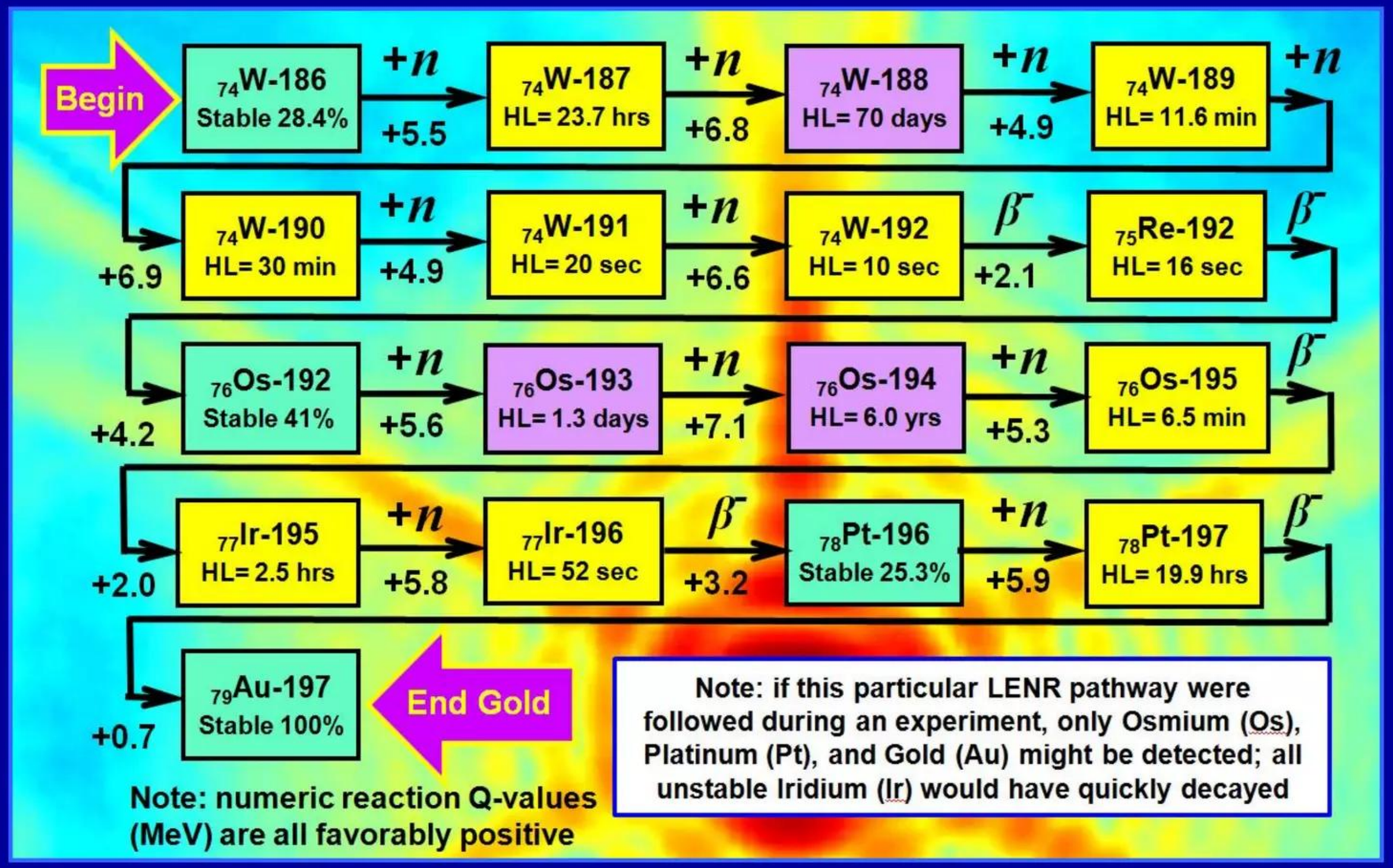
Widom-Larsen predicts Tungsten transmuted into Gold

Mitsubishi experiments confirmed existence of this predicted pathway



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2012: Mitsubishi confirms Gold transmutation pathway

MHI conducted experiments producing Platinum from Tungsten targets

Periodic Table ***n*** **capture on Tungsten (W) created Osmium (Os), Platinum (Pt)**

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	1 H				20 Ca Calcium 40.078 2-8-8-2													2 He
2	3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
3	11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
4	19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
5	37 Rb	38 Sr	39 Y	40 Zr	Nl							48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
6	55 Cs	56 Ba	57-71 La-Lu	72 Hf		74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
7	87 Fr	88 Ra	89-103 Ac-Lr	104 Rf	Db	Sg	Bh	Hs	Mt	Ds	Rg	112 Cn	113 Uut	114 Fl	115 Uup	116 Lv	117 Uus	118 Uuo

Other nonmetals
Alkali metals
Alkaline earth metals
Noble gases
Metalloids
Halogens
Transition metals
Post-transition metals
Lanthanoids
Actinoids

Transmutation

For elements with no stable isotopes, the mass number of the isotope with the longest half-life is in parentheses.

57 La	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu
89 Ac	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr

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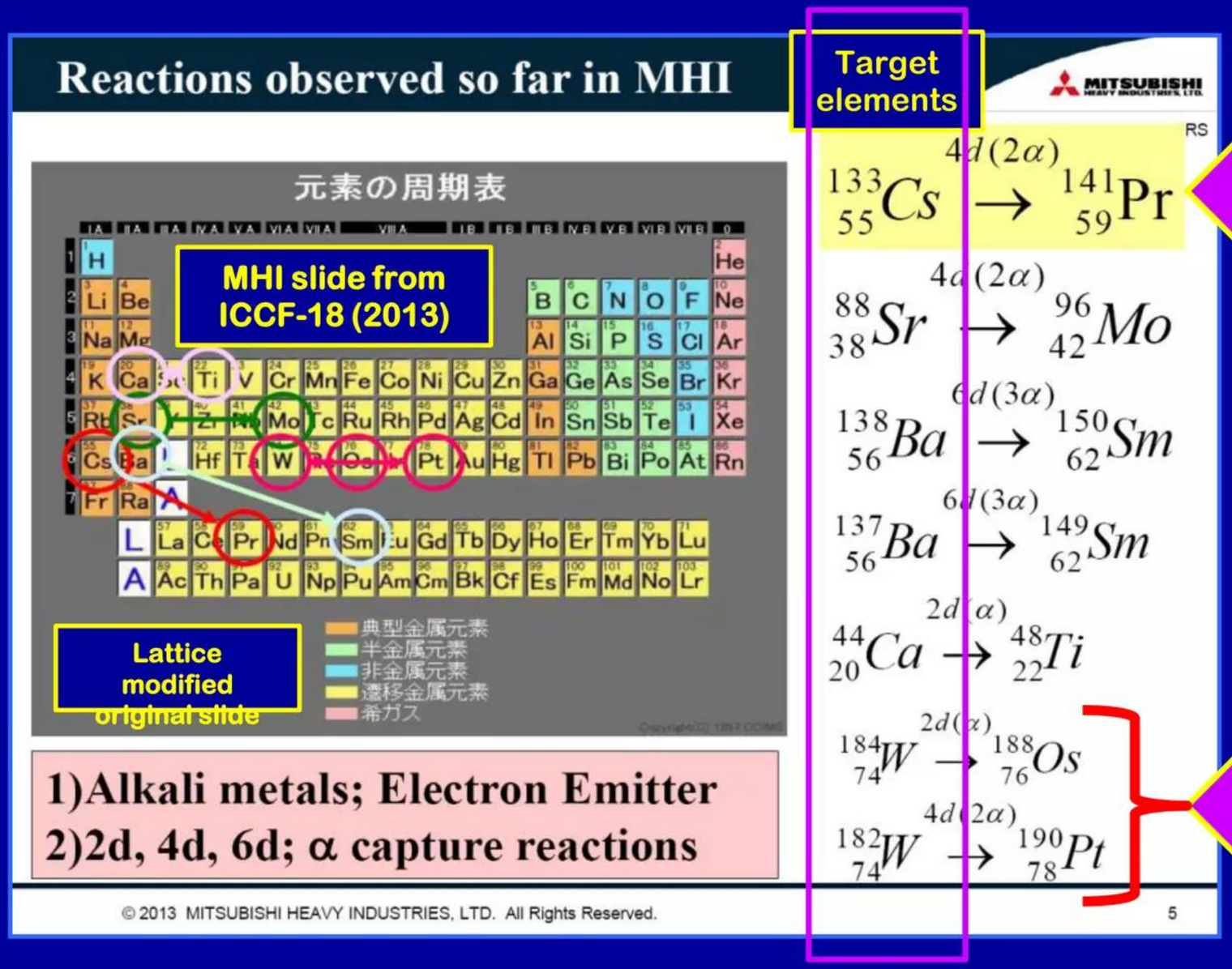
Mitsubishi experiments confirmed other LENR pathways

All of this data is well-explained by the Widom-Larsen theory of LENRs

Cesium (Cs), Strontium (Sr), Barium (Ba), Calcium (Ca), and Tungsten (W) target elements are implanted onto or into Palladium (Pd) thin-film substrate layer



Confirmed by Toyota: *JJAP* (Oct. 2013)

Reported by H. Nagaoka: *Nature* (1925)

Source: https://mospace.umsystem.edu/xmlui/bitstream/handle/10355/36792/RecentAdvancesDeuteriumPermeationPresentation.pdf?sequence=1

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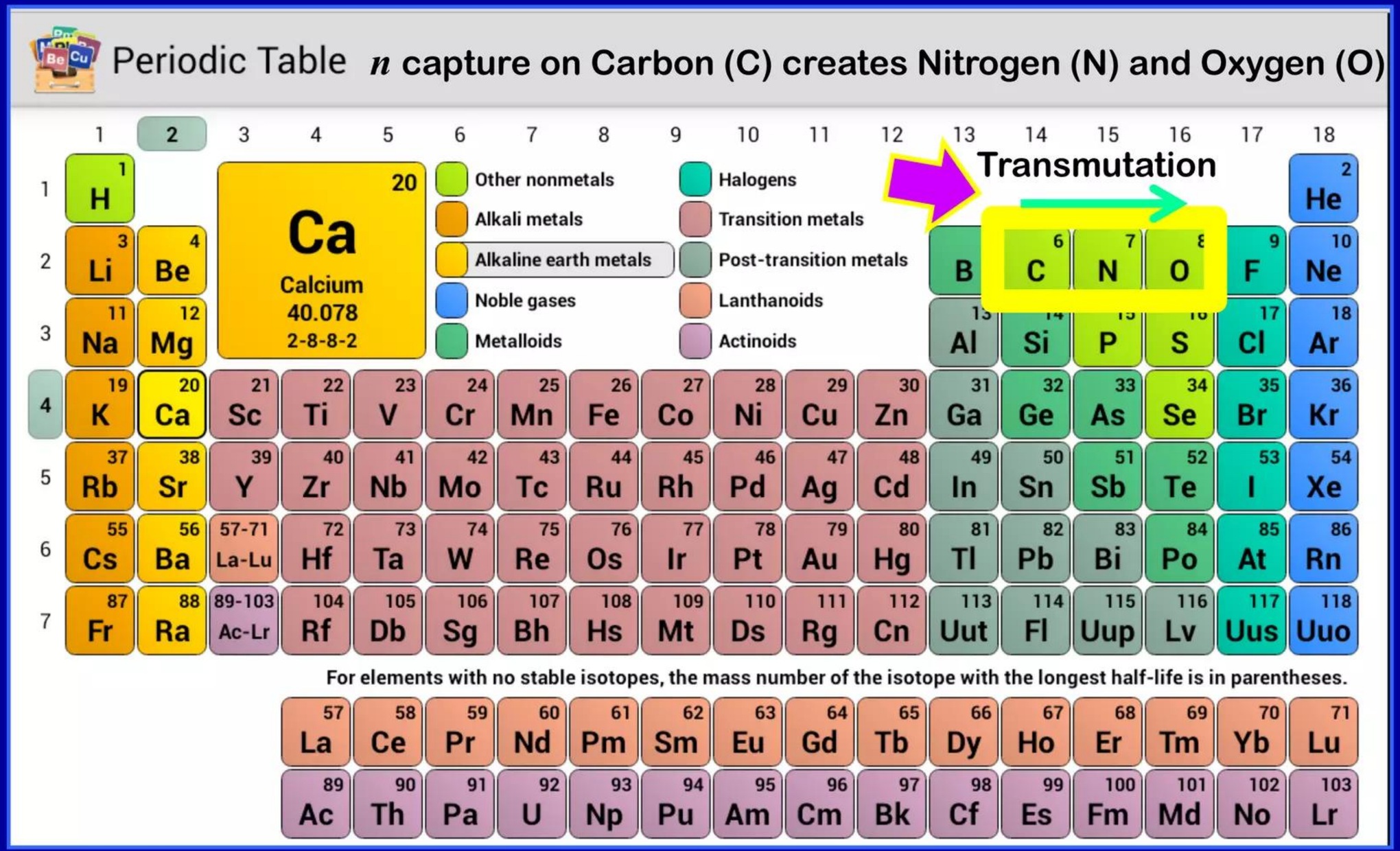
What do other LENR transmutation pathways look like?

Carbon could be processed into proper forms to make LENR target fuels



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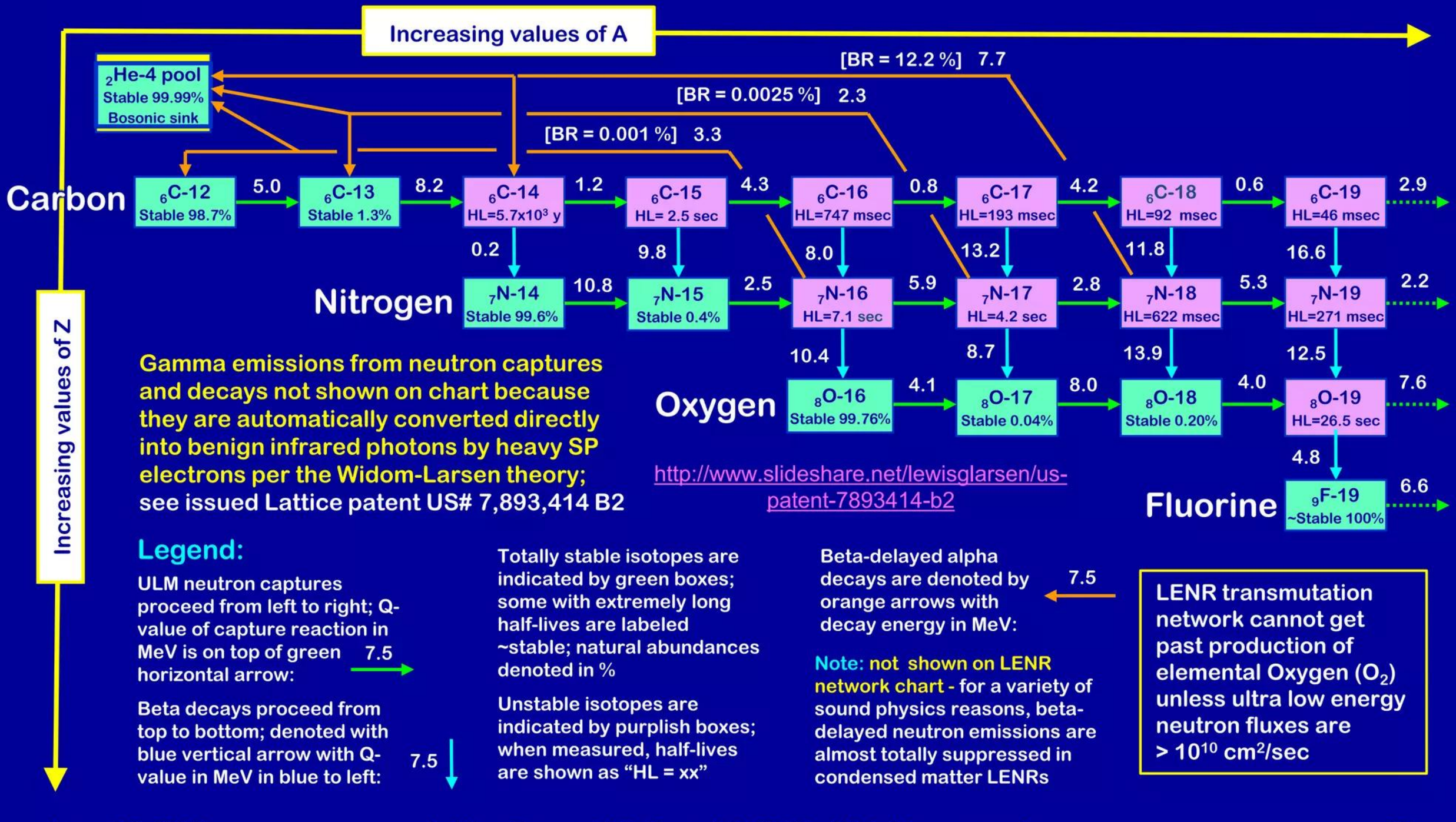
LENR C→N→O releases 5 million x more heat vs. burning

Carbon is transmuted to O_2 instead of being combusted with $O_2 \rightarrow CO_2$



Gamma emissions from neutron captures and decays not shown on chart because they are automatically converted directly into benign infrared photons by heavy SP electrons per the Widom-Larsen theory; see issued Lattice patent US# 7,893,414 B2

http://www.slideshare.net/lewisglarsen/us-patent-7893414-b2

Legend:

ULM neutron captures proceed from left to right; Q-value of capture reaction in MeV is on top of green horizontal arrow: 7.5 →

Beta decays proceed from top to bottom; denoted with blue vertical arrow with Q-value in MeV in blue to left: 7.5 ↓

Totally stable isotopes are indicated by green boxes; some with extremely long half-lives are labeled ~stable; natural abundances denoted in %

Unstable isotopes are indicated by purplish boxes; when measured, half-lives are shown as "HL = xx"

Beta-delayed alpha decays are denoted by orange arrows with decay energy in MeV: ← 7.5

Note: not shown on LENR network chart - for a variety of sound physics reasons, beta-delayed neutron emissions are almost totally suppressed in condensed matter LENRs

LENR transmutation network cannot get past production of elemental Oxygen (O_2) unless ultra low energy neutron fluxes are > 10^{10} cm^2/sec

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Future: retrofit existing coal plants with C → N → O boilers

LENRs can end combustion of coal: $CH_4 + 2\ O_2 \longrightarrow CO_2 + 2\ H_2O$ + energy

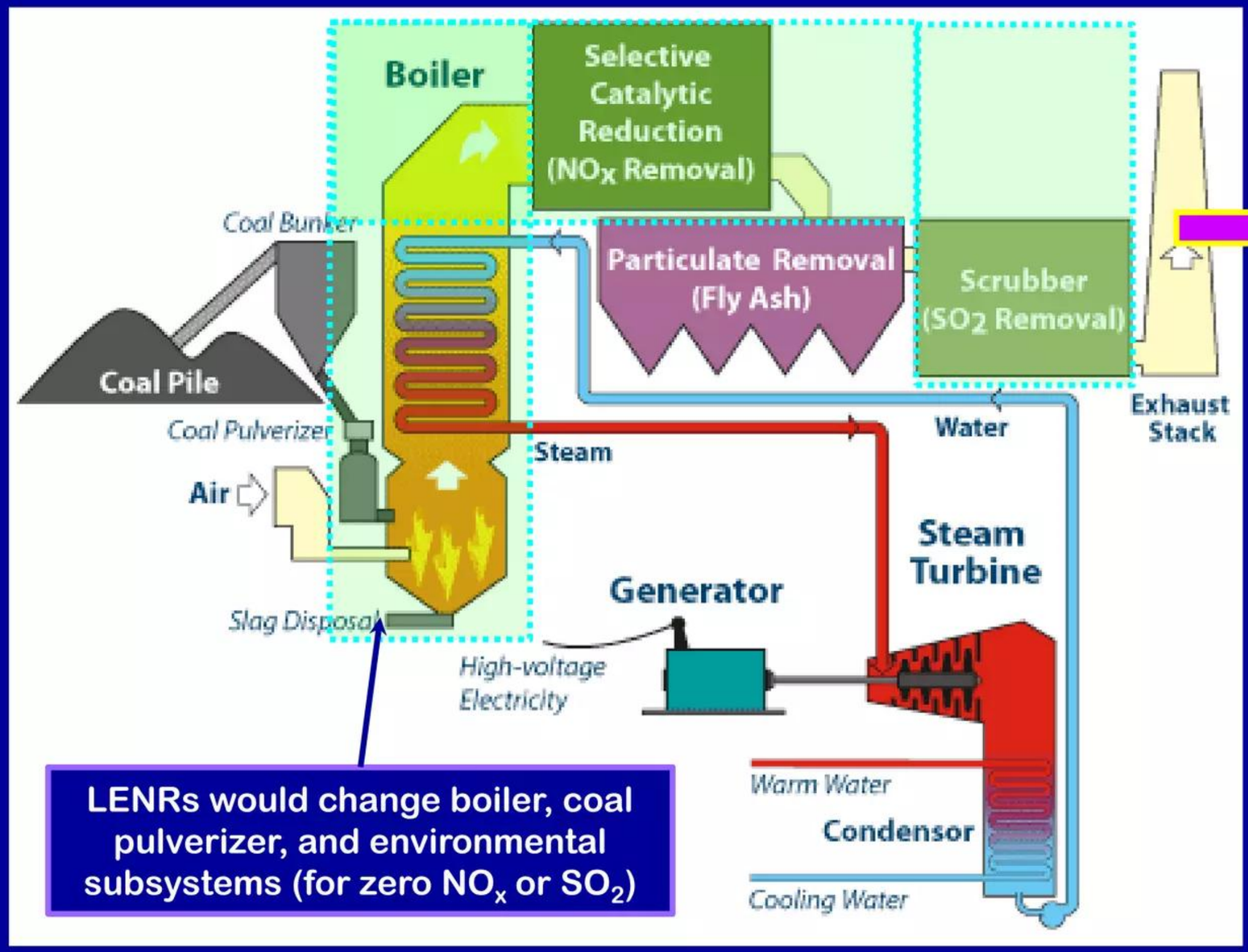
Today's inputs:

Capital $
bulk coal
air (O_2)

vs.

LENR inputs:

Capital $
Hydrogen
LENR fuel
electricity
base metals
aromatic molecules



LENRs would change boiler, coal pulverizer, and environmental subsystems (for zero NO_x or SO_2)

Today's outputs:

Heat
electricity
CO_2
NO_x and SO_2
slag, particulates

vs.

LENR outputs:

Heat
>> electricity
N_2 , O_2
waste (valuable $$$ elements)
particulates

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Economics: retrofit coal plants with LENR-powered boilers

Cost of retrofitted facility could be ~74% less than new natural gas plant

Table 2: Cost Components of Levelized Costs ($/MWh) ($2012)				Lattice estimates
Cost Component ($/MWh)	**Nuclear**	**Natural Gas (No Environmental cost)**	**Natural Gas (With $25/Ton CO_2)**	**Retrofit nat. gas or coal plants**
Capital	$ 57.78	$ 12.72	$ 12.72	**$ 2.54**
O&M	$ 10.03	$ 3.46	$ 3.46	**$ 5.02**
Fuel	$ 5.55	$ 46.99	$ 46.99	**$ 1.00**
Taxes[1]	$ 9.79	$ 10.39	$ 10.39	**$ 10.39**
Decommissioning	$ 1.46	-	-	**-0-**
Waste Disposal	$ 1.00	-	-	**$ .10**
Environmental Compliance	-		$ 9.80	**-0-**
TOTAL	**$ 85.61**	**$ 73.55**	**$ 82.35**	**$ 19.05**

Source: http://www.nuclearenergyinsider.com/nuclear-construction-summit/content-neireport.php

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LENR processes are surprisingly common in Nature

Nucleosynthesis of elements not confined to stars and supernovae

- ✓ LENRs can occur spontaneously at very low but still detectable rates in various types of systems that include: industrial processes - pyrolysis, smelting; catalytic exhaust converters installed on vehicles; and in consumers' compact fluorescent light bulbs
- ✓ LENRs occur at low rates in lightning; low energy neutron production in bolts via the Widom-Larsen collective magnetic mechanism has been effectively confirmed in data reported by Gurevich *et al.* (2012)
- ✓ LENRs could also potentiality be responsible for triggering an indeterminate subset of catastrophic thermal runaway fires/explosions known in Lithium batteries under innocuous sobriquet "field-failures"


Lightning striking Burj Khalifa in Dubai, UAE

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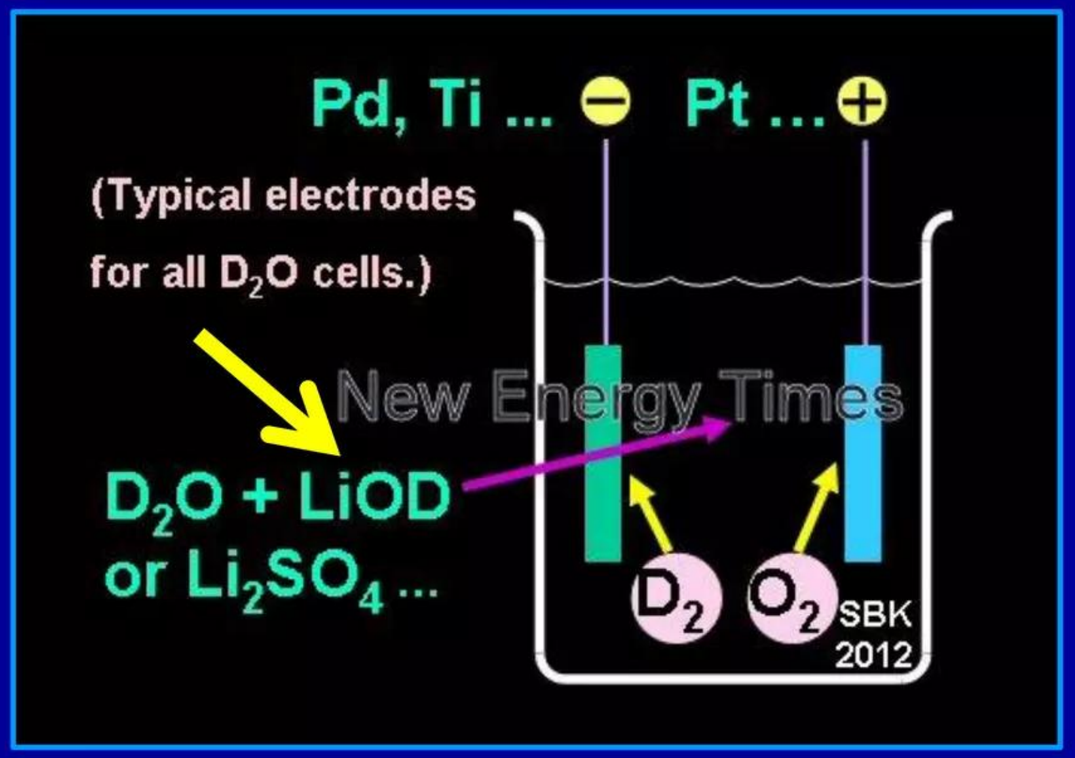
LENR electrolytic cells are like batteries being charged

Thermal runaways are more common while charging Lithium batteries

For over 20 years, some LENR researchers have been reporting experimental data that provides evidence for nuclear transmutations in electrolytic chemical cells. **Many such experiments, e.g. Miley (1996) had to have adsorbed Lithium present on cathode surfaces**

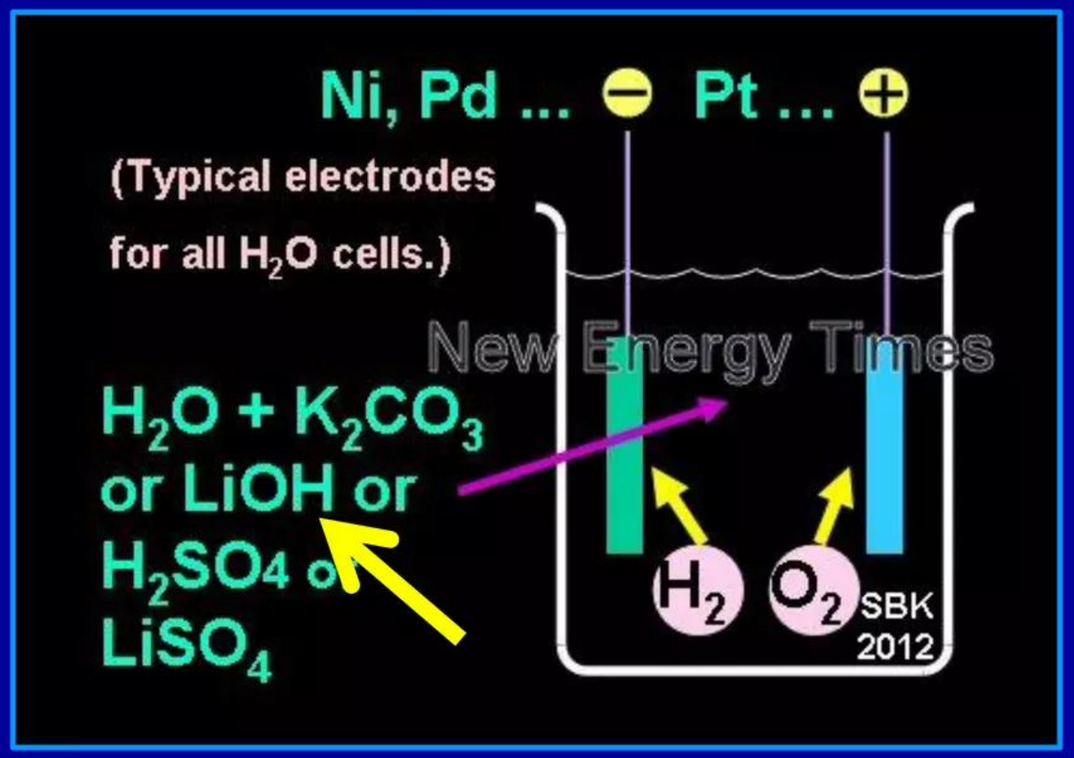
Example 1: Heavy-water P&F-type electrolytic cell

Electric current provides input energy for LENRs



Example 2: Light-water P&F-type electrolytic cell

Compounds LiOD, LiOH, Li_2SO_4 in electrolyte plate Li onto cathode



Source: html version is http://newenergytimes.com/v2/reports/Index-of-LENR-Experimental-Methodologies.shtml

pdf: http://www.slideshare.net/StevenKrivit/lenr-methodsdistributioncopyrightnewenergytimes20130522-21707257

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LENRs could be triggering thermal runaways in batteries

Subset of catastrophic incidents are perhaps caused by Lithium LENRs

- ✓ Conditions that trigger LENRs can occur in microscopic, nanoscale regions in random scattered locations on dendrites and various other types of growing nanostructures/nanoparticles found inside Lithium-based batteries
- ✓ Although radiation-free, LENRs involving neutron captures on stable Lithium isotopes are extremely energetic nuclear processes; microscopic 100 micron LENR hotspot can release 5^{+} Watts of heat in less than 400 nanoseconds; nuclear processes can raise local temps to 4,000 - 6,000^{o} C
- ✓ Micron-sized LENR-active sites that happen to be located close to plastic battery anode/cathode separators (with or without a ceramic layer) will vaporize and flash-ionize a local region of separator which can in turn trigger serious internal electrical short discharges at that particular location
- ✓ Rarely occurring LENRs can induce internal electric arcs and/or directly trigger catastrophic thermal runaways in advanced batteries having many different chemistries; some types are much more problematic than others

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Nanotechnology and LENRs are mutually intertwined

Large length scales

What was formerly thought impossible becomes possible by utilizing applied nanotechnology

Nuclear-strength electric fields in μ-sized LENR-active sites enable $e + p$ reaction

Huge array of new technological possibilities and opportunities open-up at micron to nanometer length-scales

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Technology domains are converging at nanoscales

Being driven to nm length-scales in a quest for higher energy density

Technology domain	Main purpose	Source of energy	Energy-scale	Typical rates of reactions	Temps in Centigrade	Representative examples
Electro-chemical batteries	Store electrical energy reversibly in chemical bonds	Chemical bonds	Electron Volts (eV)	Slow to moderate; typically diffusion rate-limited at various types of interfaces found inside batteries	Li batteries can generally be operated safely only at temperatures < 100° C	Large variety of different chemistries: lead-acid, alkaline, NiMH, Nickel-cadmium, Lithium-ion, $LiFePO_4$, Lithium-oxygen, etc.
Energetic materials	Thermal igniters, explosives, propellants	Chemical bonds	eVs	Fast combustion processes w. O_2, e.g., deflagration and detonation	Macroscopic peak temps max-out at ~5,000° C	Thermite reactions (burning of metals), dinitro-chloro-azido benzene, RDX, etc.
Low energy neutron reactions (LENRs)	Produce large amounts of CO_2-free thermal energy from decay particles' kinetic energies and gamma conversion to infrared	Nuclear binding energy stored inside atomic nuclei	Mega-electron Volts (MeVs) one MeV is equal to a million eVs	Nuclear reactions themselves are super-fast, i.e., picosecond and faster; decays of any resulting unstable isotopes can range from very slow on order of millions of years to fast, i.e., nanoseconds	Peak temperatures in micron-scale, short-lived LENR hotspot regions on surfaces and at interfaces typically reach ~4,000° to 6,000° C	Neutron captures on various elements and isotopes; for example, LENR neutron capture processes starting with Lithium as base fuel target can release ~27 MeV in short sequence of nuclear reactions that do not release any energetic neutron or gamma radiation

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Commercializing LENRs is highly multidisciplinary

Device design and fabrication require knowledge from multiple fields

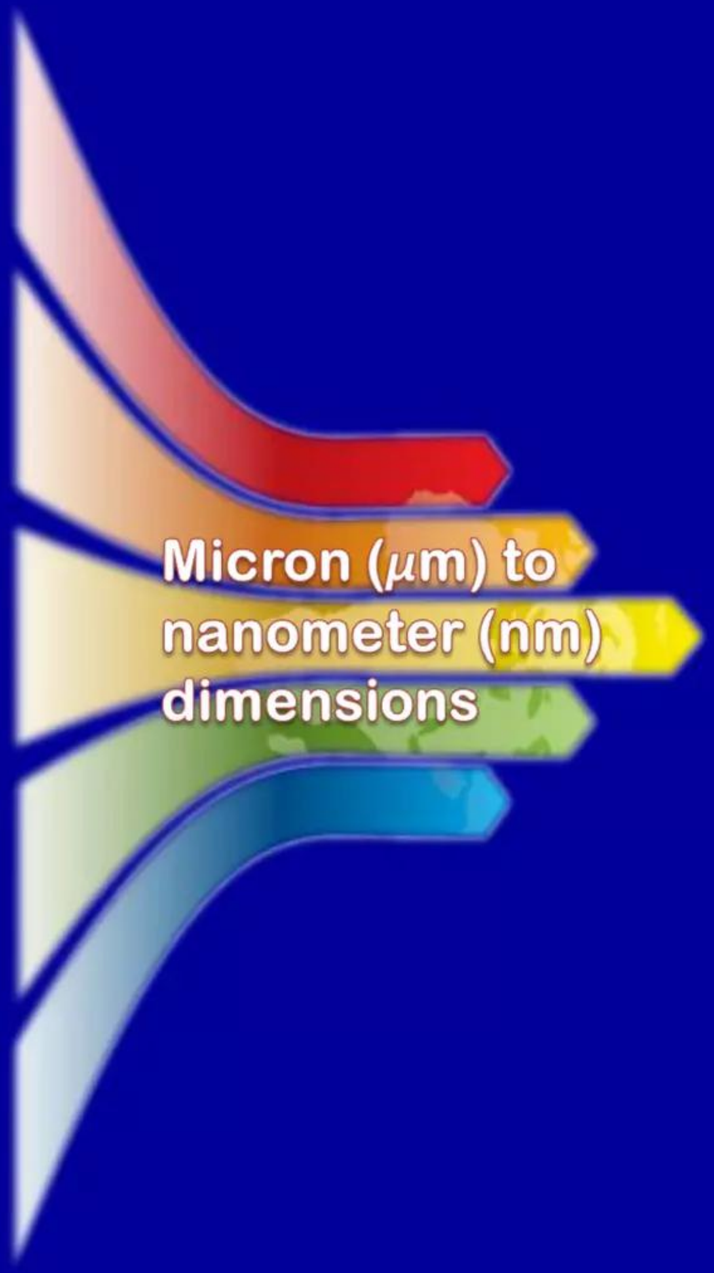
Very energetic materials

Nanotech/plasmonics

Advanced batteries

Materials science

LENRs



Eco-green ultra-high performance power generation systems for key portable, stationary, and mobile applications

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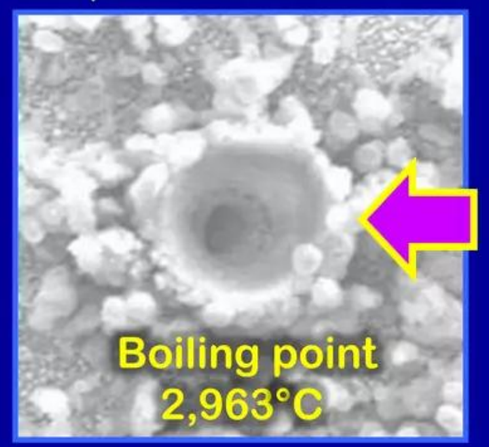
LENRs occur in microscopic spots on certain surfaces

Widom-Larsen theory shows LENRs intimately connected to nanotech

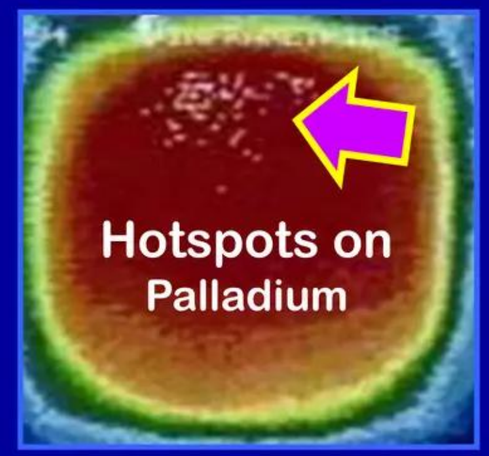
- ✓ LENRs intrinsically occur in localized micron-scale LENR-active sites on ~planar surfaces or curved surfaces of nanoparticles
- ✓ Tiny LENR-active sites only 'live' for 200 - 400 nanoseconds before being destroyed by intense heat; local peak temps range up to 4,000 - 6,000º C; LENR-active sites will spontaneously reform under right conditions in properly engineered devices
- ✓ Microscopic 100-micron LENR hotspot can release 5⁺ Watts of heat in less than 400 nanoseconds; create crater-like features on surfaces that are visible in SEM images and showing clear evidence for flash-boiling of precious and refractory metals
- ✓ Peak local LENR power density can hit > 1.0×10^{21} Joules/sec·m^3
- ✓ Control temps in LENR systems by regulating input energy and/or total area/volumetric densities of LENR-active sites

100 μ crater in Palladium



Credit: P. Boss, U.S. Navy

IR video of LENR hotspots



Credit: P. Boss, U.S. Navy

http://www.youtube.com/watch?v=OUVmOQXBS68

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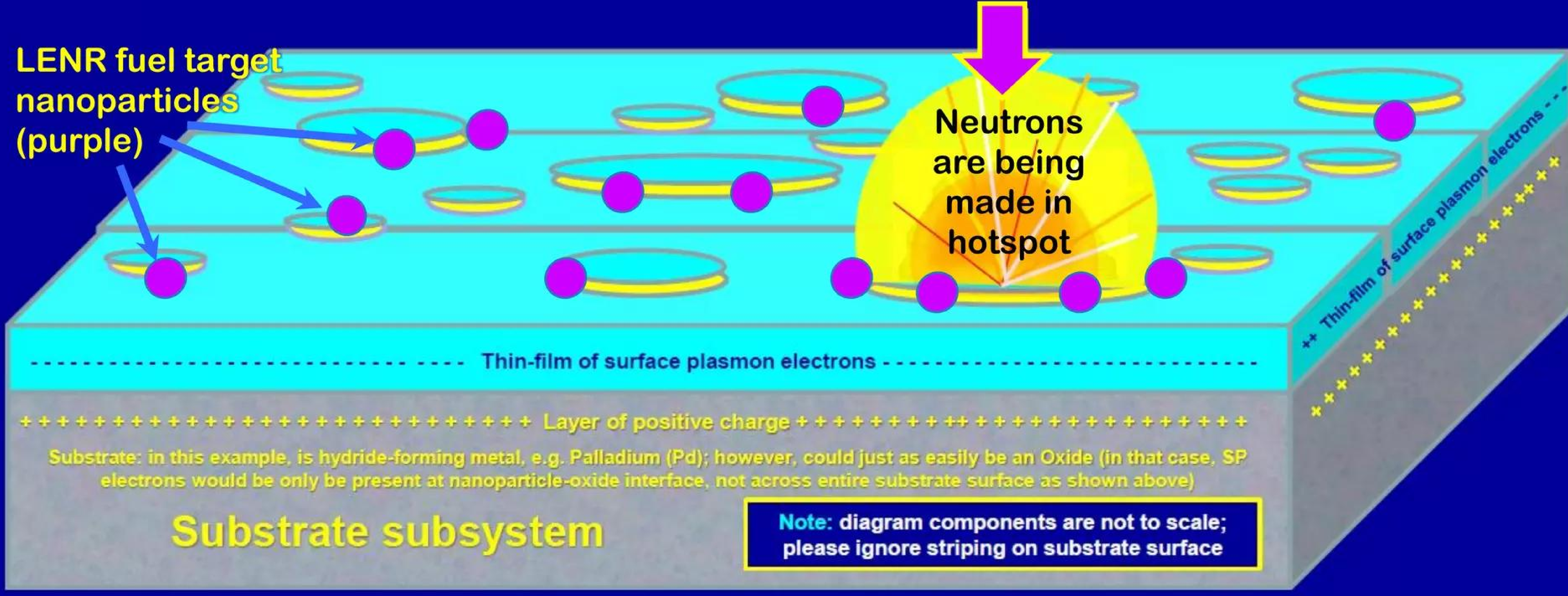
IR heat released explosively when spot goes nuclear

Fuels are positioned near active sites to absorb low energy neutrons

Releases nuclear binding energy stored in LENR fuels and transmutes elements

Explosive LENR hotspots create distinctive surface craters ~2 - 100 microns in diameter

Observed on LENR-active substrates post-experiment with scanning electron microscopes (SEM); LENR transmutation products are found in same areas with SIMS



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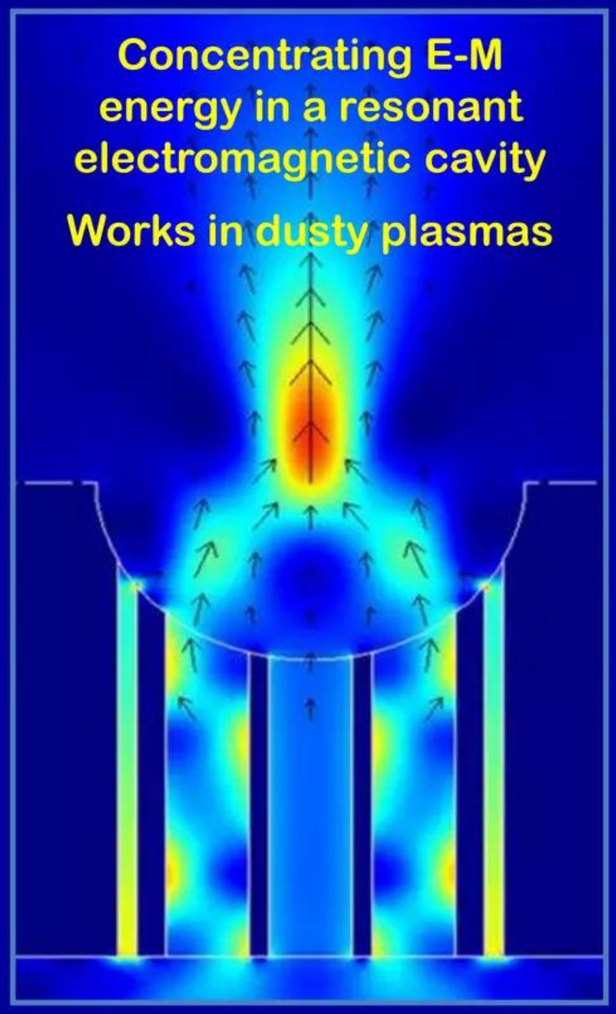
At what stage is LENR technology today?

Widom-Larsen theory enables a transition to the engineering phase

- ✓ LENRs are presently well beyond the pure basic science stage of technological development
- ✓ Widom-Larsen theory illuminates enough of the relevant device physics to permit a transition to starting early-stage product engineering phase
- ✓ LENRs situation today remarkably similar to DRAM computer memory chips during mid- to late-1960s
- ✓ Major difference with DRAMs is that as of today, nanotechnologists have already invented most of needed process and device fabrication techniques
- ✓ **Lattice believes US$60 million would enable it to develop commercial prototypes within 3 - 5 years**



Intensity distribution of beam focusing with plasmonics from B. Lee *et al.*, Seoul Nat'l. Univ. *SPIE* (2011) - arrows show direction of power flows

http://spie.org/documents/Newsroom/Imported/003435/003435_10.pdf

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LENR technology could revolutionize the world of energy

Sustainable economic growth could be achieved if it is commercialized

- ✓ While solar PV and wind are CO_2-free and extremely biosafe, their intrinsic energy densities are much lower than today's fossil fuels and inherently intermittent - not continuous - sources of electrical and thermal power
- ✓ Nuclear fission power has high energy densities, does not produce CO_2 and operates continuously; but it emits huge quantities of deadly neutron and gamma radiation during operation and produces many long-lived radwastes
- ✓ D-T nuclear fusion, while better than fission in terms of producing much less radwaste, still emits very dangerous neutron and gamma radiation during operation; also, there is still no sign of it being commercialized after 60 years of huge effort and hundreds of billions of R&D $ spent worldwide. See July 31, 2014 *Nature* story on ITER by Elizabeth Gibney: http://tinyurl.com/mlk5d5k
- ✓ Low energy neutron reactions (LENRs) are only primary energy technology on foreseeable horizon that can provide world with affordable dense green energy, connect the unconnected, and empower billions of powerless people

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Additional references

"What happens to the world if commercial LENR power systems can achieve >10x chemical energy densities? … Revolution --- here is how and why"
L. Larsen, Lattice Energy LLC, February 16, 2014 [93 slides]

http://www.slideshare.net/lewisglarsen/lattice-energy-llc-revolutionary-lenrs-could-power-future-aircraft-and-other-systems-feb-16-2014

Index to large collection of documents about LENR theory, experimental data, and the technology:

"Index to key concepts and documents" v. #18 [heavily hyperlinked to online original source documents]
L. Larsen, Lattice Energy LLC, May 28, 2013 [115 slides] Updated and revised through April 19, 2014

http://www.slideshare.net/lewisglarsen/lattice-energy-llc-index-to-documents-re-widomlarsen-theory-of-lenrsmay-28-2013

Review paper covers basic theoretical aspects of Widom-Larsen many-body collective LENR theory:

"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)

Abstract: "Under special circumstances, electromagnetic and weak interactions can induce low-energy nuclear reactions to occur with observable rates for a variety of processes. A common element in all these applications is that the electromagnetic energy stored in many relatively slow-moving electrons can (under appropriate circumstances) be collectively transferred into fewer, much faster electrons with energies sufficient for the latter to combine with protons (or deuterons, if present) to produce neutrons via weak interactions. The produced neutrons can then initiate low-energy nuclear reactions through further nuclear transmutations. The aim of this paper is to extend and enlarge upon various examples analyzed previously, present order of magnitude estimates for each and to illuminate a common unifying theme amongst all of them."

http://www.ias.ac.in/pramana/v75/p617/fulltext.pdf