

**High-Efficiency Thermoelectric Devices
Integrated with Nuclear Heat Sources
For Energy Dense, Long-Lived Portable Power**

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Commercializing a “Green” Next Generation Energy Source

February 20, 2004

Long Association between Thermoelectric Devices and Nuclear Heat Sources

- **Used in applications requiring energy dense, long-lived sources of portable electrical power**
- **Nuclear heat sources needed when:**
 - ✓ **Interim “refueling” either practically impossible or onerous logistical “tail”**
 - ✓ **Application performance requirements cannot be met by existing chemically-based battery or fuel cell technologies**
 - ✓ **Applications require high energy density and/or long operating lifetimes**
- **Radioisotopes have been integrated with thermoelectrics as RTGs to satisfy mainly space-based power generation applications**
- **Very limited terrestrial market applications for RTGs - - serious environmental and safety issues**

Performance Parameters/Estimated Costs of Representative Radioisotope Heat Sources

Element – Isotope	Half-Life (years)	Watts/g (thermal)	Est. Cost in \$/Watt (thermal)	\$/kilowatt (thermal)	\$ per Watt /year over useful life* (thermal)	\$ per kilowatt /year (thermal) over useful life*, i.e. 2 half-lives	\$ per kWh (thermal) over useful life*
Polonium- 210	0.378	141	\$570	\$570,000	\$750	\$750,000	\$86
Plutonium-238	86.8	0.55	\$3,000	\$3,000,000	\$17	\$17,000	\$2
Cesium -144	0.781	25	\$15	\$15,000	\$10	\$10,000	\$1
Strontium - 90	28.0	0.93	\$250	\$250,000	\$5	\$5,000	\$0.50
Curium - 242	0.445	120	\$495	\$495,000	\$556	\$556,000	\$64

Source for Watts/g and \$/Watt cost data: Northwestern University, Spacecraft Power Systems Project

Note: Outside of Russia, Plutonium-238 has been the most commonly used radioisotope in RTGs

Limited Market Applications for Existing RTGs

- **RTGs have been highly successful in meeting performance requirements of targeted applications**
- **Previous table suggests some radioisotope heat sources can compete (cost per kWh) with portable chemical power sources**
- **Terrestrial civilian and military applications require dense and/or long-lived sources of portable electrical power**
- **Existing RTG technologies cannot compete effectively with chemical power sources in terrestrial applications because:**
 - ✓ **Long-lived radioisotopes are hazardous to the environment and biologically dangerous for human beings**
 - ✓ **Insoluble environmental, political, and safety issues prevent governments and companies from widespread deployment of existing RTG technologies**

Potential to Develop a New, Safe Alternative to Existing Radioisotope Heat Sources

- **Alternative called Low Energy Nuclear Reactions (“LENRs”)**
- **“LENRs” is a broad descriptive term that covers a new, complex family of “green”, heat-producing nuclear reactions involving deuterium and hydrogen atoms in and around solid-state metallic lattices**
- **LENRs remain very controversial area of science; many physicists remain highly skeptical**
- **Mainstream scientific critics argue: since LENR experiments do not typically produce “normal” nuclear products and are not easily reproducible, LENRs are not “real” and “cold fusion” is “junk science”**
- **The critics are wrong. You can argue about whether this technology can be successfully commercialized, but the underlying science is real**

Scientific Reality of LENRs has been Established

- **By 2004, various types of LENRs unequivocally confirmed in scores of excellent experiments by:**
 - ✓ **Continuing research efforts in more than 6 countries**
 - ✓ **Public/private companies (e.g. Mitsubishi Heavy Industries in Japan, Lattice Energy LLC, SRI International, Clean Energy Technologies)**
 - ✓ **Government laboratories (e.g. U.S. Navy, Los Alamos National Laboratory, ENEA in Italy)**
 - ✓ **Academic researchers (e.g. Dr. George Miley at the University of Illinois, Dr. John Dash at Portland State University, numerous universities and institutes in Japan, Russia, China, and France)**
 - ✓ **Number of individual scientists (e.g. Dr. Edmund Storms, Dennis Letts) etc**
- **Difficulties with experimental reproducibility still commonplace, but certain types of LENR experiments have demonstrated repeatability of 70% - 80% or higher. Lattice has achieved excellent levels of repeatability with certain experimental configurations**

Powerful Evidence that LENRs are Real

- You can argue about excess heat measurements and ponder near absence of “normal” nuclear products, but transmutation experiments involving LENRs are irrefutable
- Excellent, definitive transmutation experiments reported by Mitsubishi
 - ✓ Iwamura et al, Advanced Technology Research Center, Mitsubishi Heavy Industries, titled, “Elemental Analyses of Pd Complexes: Effects of D₂ Gas Permeation” that appeared in the *Japanese Journal of Applied Physics* (refereed), Vol. 41 (July 2002) pp. 4642 – 4650
- For additional references and downloadable papers, visit repository for LENR-related information on the Web at <http://www.lenr-canr.org>
- In most parts of the world, the private sector, not government, is leading the way with ongoing investments in LENR research --- e.g. Lattice Energy LLC and Mitsubishi Heavy Industries

Distinguishing Characteristics of LENRs

- **Nuclear reactions comprising LENRs do not follow traditional fusion and fission channels due to a unique energy distribution**
- **LENRs produce a variety of relatively benign nuclear reaction products comprising stable isotopes, small fluxes of alpha/beta-particles and soft X-rays, and significant amounts of heat**
- **LENRs normally do not produce energetic neutrons, hard radiation (energetic gamma- and X-rays) or dangerous, long-lived radioisotopes**
- **These “green” characteristics distinguish LENRs from “normal” nuclear reactions**

Lattice's Commercialization Goals

- **Funded by the private sector, Lattice's business goal is to commercialize its proprietary LENR technologies to:**
 - ✓ **Develop compact, energy-dense, long-lived heat sources**
 - ✓ **For use in a wide array of military and civilian portable power generation applications**

- **Lattice believes that commercial versions of its thin-film LENR nano devices:**
 - ✓ **Can be developed and integrated with high-efficiency thermoelectrics**
 - ✓ **To provide highly competitive portable power sources**

Market Opportunities

- **Unlike existing RTGs, potential market size could be very large for compact portable power devices based on LENR heat sources**
- **Broad range of high-volume military and civilian portable power generation applications**
- **Increasing demand for solutions that provide longer operating lifetimes and higher performance**
- **These demands cannot be fully satisfied by existing chemically-based, portable power generation technologies:**
 - ✓ **Advanced Batteries**
 - ✓ **Fuel Cells**
 - ✓ **Miniature IC Engines and Catalytic Microgenerators**
- **LENR devices integrated with TEs offer a potential solution**

High-Growth, High-Volume Application Requirements

- **Requirements for these applications (e.g. “high-drain” devices) include:**
 - ✓ **Energy dense, portable, long-lived power sources**
 - ✓ **More-or-less continuous electrical output**
 - ✓ **Electrical power outputs ranging from several milliWatts up to about 30 Watts**
 - ✓ **Operating lifetimes ranging from 48 hours to several thousand hours**
 - ✓ **Minimize need for interim refueling or recharging**
- **Requirements span “no man’s land” between several-hours-to-a-few-days longevity of chemical power sources to months-to-many-years of RTGs**
- **Battery and fuel cell companies striving to improve their technologies; performance enhancements likely be incremental, not fundamental**
- **LENRs offer potential for orders of magnitude improvements**

Pricing of Power in Portable Devices

Device size and total power output DECREASE along this axis; device unit volumes generally go UP substantially as size/output decreases

Battery-like Device Market Pricing	Price \$/kWh
Long-lived nanopower for wireless sensors and nanodevices (Lattice estimate)	~ 3,000.00
Nanopower for MEMS and somewhat larger devices (Lattice estimate)	~ 2,000.00
Integrated power for small, portable electronic devices; small, uninterruptible backup power units	~ 1,000.00
Commodity AAA Non-rechargeable	890.00
Commodity AA Non-rechargeable	330.00
Commodity C Non-rechargeable	180.00
Commodity D Non-rechargeable	90.00
Commodity Li-ion 18650 rechargeable	24.00
Commodity NiMH AA rechargeable	19.00
Commodity Lead Acid (plastic) rechargeable	9.00
BB-390 military NiMH rechargeable	8.00
Commodity NiCd AA rechargeable	7.50
Bulk AC power from a utility (wall socket cost)	0.05 - 0.10

Source for Battery Data: "The Fuel Cell: is it ready?" by Isidor Buchmann, Cadex Electronics, February 2001 (see <http://www.buchmann.ca/Article1-Page1.asp>)

Comparative Energy Densities

LENRs Versus Chemical Energy Sources: Batteries, Fuel Cells, and Microgenerators	
Energy Source	Approximate Energy Density (Watt*hours/kg)
Alkaline Battery	164
Lithium Battery	329
Zinc-Air Battery	460
Direct Methanol Fuel Cell (efficiency = 35%)	1,680
Gas Burning Microgenerator (efficiency = 20%)	2,300
Pure Methanol	5,930
Pure Gasoline	11,500
LENRs (based on Lattice's rough assumption of an <u>average</u> of 0.5 MeV per nuclear reaction)	57,500,000 theoretical estimate – see discussion below

Energy Density Advantages of LENRs

- Only fractions of theoretically possible LENR energy densities are likely to be realized in commercial LENR heat sources
- Even with major technological improvements in batteries, fuel cells, and microgenerators, they cannot match realizable energy densities of modestly optimized LENR power sources
- Recent experimental measurements of LENR energy densities:
 - ✓ Lattice and other research groups measured overall heat fluxes (Watts per cc) in some LENR devices that exceeded those found in fuel rods of nuclear reactors
 - ✓ Lattice and another group measured and calculated heat fluxes from nano-sized nuclear-active sites on LENR devices; estimated heat fluxes from those sites were in the MegaWatts/cc range

Longevity Advantages of LENRs

- **High energy densities of LENRs could potentially reduce device longevity; large accumulated “doses” of extreme local heating and transmutations can alter LENR device materials**
- **Lattice and others can fabricate miniature thin-film LENR heat sources that routinely produce milliWatts to a Watt of excess heat for at least 48 to 72 hours**
- **Lattice and other groups have occasionally been able to fabricate LENR devices that produce heat for 500 to 1,000 hours**
- **By contrast, typical commodity AA alkaline battery subjected to constant power draw of about 100 milliWatts will have a useful operating life of less than 20 hours**

Status of Commercialization of LENRs

- **Operating lifetimes and gross excess heat output of LENR devices are already in the ballpark necessary for commercialization**
- **“Gains” achieved today in LENR devices need improvement. Must exceed breakeven point, i.e. replace minimum electrical input power necessary for starting-up and operating the device continuously**
- **Most LENR research groups now observe excess heat gains $< 1.0x$**
- **Reproducible gains $> 3.0x$ to $5.0x$ necessary for commercialization**
- **Required minimum gain depends heavily on TE conversion efficiency; the higher the TE efficiency, the lower the needed LENR gain**
- **Overall reproducibility of heat production needs substantial improvement; 70% - 80% success rates not high enough**
- **Optimization of materials, fabrication techniques, device-level designs, and systems integration will follow**

Closing Remarks

- **LENRs and high-efficiency thermoelectrics are synergistic technologies**
- **US military likely to be early adopter of LENR-based technologies; shortages of batteries triggered by use of numerous electronic devices in 24X7 combat caused serious logistics readiness crisis during Iraq war**
- **Current global LENR R&D spending is probably less than \$25 million per year. In spite of widespread skepticism, LENRs moving gradually toward commercialization. Most funding now coming from the private sector**
- **Ultimately, LENRs are a highly scalable technology ---- using device arrays and volumetric increases, system-level power outputs based on TEs could eventually be boosted to tens of kilowatts --- widen range of applications**

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