To assure continued and expanding funding in an increasingly cost-conscious, results-oriented world economy, "cold fusion" needs solid proof of commercial feasibility. Excess heat calculations are of little use in convincing nonscientific skeptics. Heat alone, at low temperatures, does not have the "medium of exchange" value of electrical power. Proof of commercial viability has three critical dimensions which must meet certain minimums:

- The temperature must reach 175 to 200°C – high enough to allow reasonably efficient (in the range of 15-20%) conversion to mechanical/electrical power.

- The system power levels must reach at least 5 to 10 kw of thermal output to demonstrate conversion to self power plus provide useful electrical energy for other functions.

- The system must operate continuously for weeks to months with short lag times to start up or shut down.

To date, world wide, most cold fusion investigations have been attempts to confirm and expand understanding of the Fleischmann-Pons Effect (FPE) at its basic levels. This research to corroborate FPE - with notable exceptions - has three common characteristics:

- Most FPE experiments have been conducted at or near ambient conditions of temperature and pressure, many in open cells.

- The experiments have been small in scale with minimal standardization of design.

- These experiments produced small thermal outputs and low excess energy ratios.

Despite the many technical (and other) obstacles in this field, the research now has clearly revealed these empirical facts:

- Nuclear reactions can indeed occur in electrolytic systems;

- The energy released in these reactions occurs primarily as heat.
The major byproduct in palladium-deuterium systems is ordinary helium; [1]

- Excess energy ratios exceeding 10:1 are possible;

- The energy density can exceed three kilowatts per cubic centimeter;

- The reaction rate increases nonlinearly with increasing temperature. [2]

These results hint at the potential power yields from cold fusion. They also show that safety precautions developed for electrochemical research can no longer be considered sufficient for FPE studies. The various accidents and events arising from open cells have led Fleischmann, Pons and others to issue warnings emphasizing the danger of closed systems. [3]

However, if cold fusion is to ever reach its potential, closing and pressurizing the research cells is necessary. This calls for a much greater ability to contain and control cold fusion events. Safety must be the highest priority in the laboratory and thus, in the design and construction of experimental equipment. Good design must allow for radioactive products, high pressures at high temperatures, coolant circulation and the ability to easily maintain experimental protocols.

CONTAINMENT.
Cold fusion experiments often produce minor amounts of neutrons and tritium.[3,4] As these reactions are scaled up, this amount will increase, presumably proportionally.

Neutrons can be absorbed by the appropriate shielding. Tritium, on the other hand, is a lasting hazard that must be handled, stored and disposed of in carefully regulated ways. This would argue for a thermodynamically closed cell configuration so that any tritium generated would be catalytically recombined with oxygen and returned to the electrolyte. Tritiated water is actually more biologically dangerous than the gas, but easier to contain. All used electrolyte should be treated as low-level radiologically hazardous waste until tested.

HEAT AND PRESSURE EVENTS.
A pressurized cell is also necessary if the system is to operate at temperatures greater than 100°C. Closing and pressurizing the cell adds safety risk to laboratory and personnel. In a fixed volume, steam will reach pressures that exceed 200 atmospheres as the temperature rises over 375°C. This temperature could quickly be reached in a cell operating at a lower temperature, given the high power density possible and the positive temperature coefficient findings.

The result is the very real possibility of thermal runaway reactions. These appear to have occurred - even in open cells. In closed cells the results are much more drastic - a steam explosion. To avoid this happening, any closed FPE cell must be designed to withstand sudden surges to the critical (maximum) pressure of its electrolyte. At
minimum, an oversized relief valve must be installed.

Also in closed cell systems, the failure of the catalyst to recombine the gases generated by electrolysis leads to extremely high pressures, higher than the maximum possible from steam but developed over a longer time. This type of overpressure event is best sensed and avoided, however the pressure could be controlled with a safety relief valve. The ignition of the unrecombined hydrogen and oxygen is a possible failure mode – particularly in the electrically active, thermally hot environment of a cold fusion reaction cell. This ignition results in an abrupt release of chemical energy with a pressure pulse rising to 10 times the starting pressure, capable of generating a significant shock wave. The strength requirements of the vessel must be based on the worst case.

COOLING.
The closed, high temperature FPE power cell requires a large cooling capacity. [5] A 3kw/cc energy density provides sufficient energy to vaporize that cc of paladium in two minutes. Since cooling occurs most efficiently across thin walls, this conflicts with the need for a thick, strong cell walls.

A prudent cooling system design would provide a modified pool boiling arrangement so that the flow rate of coolant past the heat exchange surface of the cathode is convectively driven by the heat flux emanating from the cathode. This should prevent or control thermal runaway reactions. A pressurized reservoir of coolant, gravity-fed to the cell, would allow time for an orderly shutdown in the event of a cooling pump failure.

The above shows a requirement for a relatively large volume of cooling fluid. In general, the more and the milder the coolant, the better. The electrolyte is a poor choice due to its highly corrosive composition, high pressure, potential for tritium contamination and high cost. Therefore, a second fluid is needed in a self-contained, pressurized system separate from the electrolyte. It must circulate through coolant passages in the high pressure chamber, close to the cathode.

There are only a few ways to accomplish this, topologically speaking. One would be with a central hollow palladium cathode lined with silver to prevent hydrogen diffusion. With this design solution, the onset of film boiling in the coolant would limit the maximum heat transfer rate. This limits the thickness of the palladium on the coolant tube and thus limits the over-all power density possible with this configuration.

The ETC
To avoid these limits, while at the same time maintaining the simple rotationally symmetric electrical field configuration of the original FP experiment, a topological inversion lies at the heart the ETC. An externally silvered palladium ring cathode surrounds a central anode. The outer, silver surface of this cathode ring, which is axially tapered, is in contact with a similarly tapered silver shell for electrical and
thermal conductive energy transfer. In this way, the heat exchange surface can increase in area outward from the source of heat.

The Electrolytic Thermal Cell™ (ETC) reflects the goal of assured safe operation at temperatures to 350°C, pressures to 3,500 psi (250 atm) and electrolysis input powers up to 1 kw. It has a continuous cooling capacity of 20 kw with a peak capacity of 100 kjoules/second for 30 seconds. Layering of progressively redundant safety systems assures graceful failure modes to extreme conditions.

The core of the ETC is a high pressure chamber of stainless steel, 13cm outside diameter by 4.5cm bore. At its top, it incorporates high-capacity, fail-safe pressure relief plus instrumentation feed-throughs. It holds a structurally-embedded cast-silver thermal dissipator in its lower section. The finned dissipator is immersed in and tightly coupled to the calorimeter (boiler) section, which has an integrated, pressurized coolant (working fluid) reservoir. The cooling fins are thick enough at their roots to allow temperature and vibration sensors to be embedded nearly in contact with the cathode. Surrounding and bracing the fins is a heavy stainless ring which carries three internal electrical heating elements. The heaters can bring the reaction chamber to operating temperature or can calibrate the calorimeter up to 20kw.

A coolant such as water, liquid nitrogen or a fluorocarbon like trifluoroethanol (CF₃CH₂OH₂0) is thermosiphoned from the reservoir past the thermal dissipator, where boiling occurs. The resulting vapor carries entrained, hot droplets that are centrifugally removed and returned to the boiler. After a secondary demisting stage, the saturated hot vapor exits the ETC to pass through flow measurement or energy conversion devices and into condensing coils. Recondensed coolant, approximately 2 litres/minute at maximum power, is pumped back into the boiler reservoir, when called for by level sensors. The boiler working pressure can be as high as 750 psi (50 atm). Controlling this pressure at the boiler outlet sets the operating temperature of the cathode.

Containment vessels thermally isolate the experiment while protecting the experimenter and laboratory from overpressure events. The 55cm diameter outer containment vessel encloses the entire calorimeter, electrolysis chamber and inner containment vessel. The inner containment vessel, 30cm diameter, encloses only the upper portion of the high-pressure chamber. It is designed to receive the blow-off from the high-pressure relief and has 40 times the volume of the electrolytic cell.

Normally at a rough vacuum, both containment vessels automatically vent and reseal when their pressures rise past a threshold. Both are double walled, high-vacuum insulated, heavy gauge cold-formed stainless steel - as are the calorimeter (boiler/reservoir) walls. Gaskets, spacers, washers, bolts and nuts are also stainless. The total heat loss rate is estimated at a maximum of 150 watts at 250°C.

The annular space between the inner components and the outer vessel, evacuated during operation, can also hold a 5cm thick shell of neutron moderation materials,
with absorptive additives. The insulating walls of the outer containment vessel can be filled with a proportional counting gas and strung with beaded wires to allow neutron detection by silver activation over a hemisphere approximately centered on the cell.

Access to the electrolysis chamber is made through 10cm diameter ports at the top of the outer and inner containment vessels. These ports also hold feedthroughs for instrumentation. Electrolysis power is supplied through a fail-safe connector within the bottommost port. Contact in the high current connector (100 Amp continuous, 2,000 Amp surge) is mechanically established by a collapsing stainless bellows only when rough vacuum is attained within the ETC evacuation region. If overpressure or leakage causes loss of vacuum above a threshold level, a pilot valve causes the safety switch bellows to extend, shutting down the main electrolysis current. An auxiliary contact is closed as the main opens, allowing a trickle charge to hold the hydrogen in the cathode or a reverse charge to flush it out.

The anode conductor, a 0.5cm diameter silver rod, 25cm long, insulated with teflon and ceramic, centered inside a one centimeter diameter silver tube brings current to the cell. Heat which would be lost via and within the coaxial power conductor is largely absorbed by the incoming coolant flow and thus kept inside the calorimeter. This coaxial design also permits sub-microsecond pulse rise times of the input power.

The power conductor is a part of the removable electrochemical cartridge. The rod does double duty by transmitting rotary motion to the high-pressure cell. Threads convert this to non-rotating vertical movement of the tapered platinum mesh anode. The electrodes can be brought into contact in order to center the anode and also to make reference measurements. The spacing between the anode and cathode can be adjusted with a servomotor driving the external shaft. The gear reduction and threads combine to move the anode a calculated 0.55 micron per degree of actuator shaft rotation. It is thought that minimizing the electrode spacing via a feedback system could have beneficial effects on performance.

All active electrochemical components (i.e. electrolyte, cathode, anode, reference electrode and recombiners) are contained in sealed silver-shelled cartridges which have an internal volume of 125cc and use 10 to 12cc of electrolyte. The electrochemical cartridges can be inserted or removed via the top access ports of the ETC containment vessels. The interchangeable cartridges reduce experiment turnaround and cell maintenance time. Low current precharging of multiple cartridges outside the ETC can be readily accomplished. The cartridges remain sealed during exchange to prevent pre- and post-experiment material contamination and/or loss of electrolyte. A simple aluminum or plastic form is provided to mold a silicone rubber seal around the cathode ring after it is placed in the silver shell of the cartridge being assembled. This operation can be performed by NRG if desired. Custom cathodes can be supplied as well, with ring dimensions, alloys and metallurgical treatments to specifications. NRG will also provide complete post-experiment analysis services and cartridge shipping containers.
In order to certify that the Electrolytic Thermal Cell is safe within its operational ratings, manufacturing will be done in batches. All materials in each batch will be traceable. Each unit will receive thorough inspections and certain non-destructive testing. Samples selected from the manufacturing run will be subjected to a battery of tests, including the testing to destruction of a few units. Very much depends on attention to details. We must be confident before units are shipped to other researchers, and before we begin our own high-power experiments.

The ETC is designed for versatility. For example, following preloading of the cathode through electrolysis, the cell may be evacuated and high voltage glow discharge experiments initiated. The ETC is made entirely of magnetically transparent materials which facilitates experiments involving external fields. It should be noted that the ETC is not only a calorimeter, but it is also a pressurized power reactor. Development of compatible Rankine cycle conversion equipment progresses.