PROJECT TITLE:	Cost Effective Acoustic Stirling Cryocooler with Flexibly Attached Remote Coldhead
ORGANIZATION:	CFIC-Qdrive
PRESENTERS:	John Corey, President
FY 2008 FUNDING:	$358,271

Overall Project Purpose and Objectives:

This project addresses the need for practical cryogenic refrigeration (cryocooling) to realize the benefits of high-temperature superconductivity (HTS) in the electrical power grid infrastructure. Present alternatives do not combine the reliability, efficiency, cost, and interface configuration to support HTS transformers, transmission lines and other devices beyond the demonstration phase and into commercial service.

HTS-scale FAR-type acoustic-Stirling coolers, the focus of this Phase II project, can do it; combining high reliability, efficiency, and a flexibly-connected coldfinger interface that is a drop-in replacement for many uses where G-M coolers are now used for demonstration and the entire cooler mass cannot be practically supported over a cryostat.

The goal of the project is to extend this configuration form the benchtop scale (10W @ 77K) to units aimed at HTS-3 & HTS-4 (300 and 1,000W @ 65-80K, per DoE HTS Cryogenics Roadmap). Specific objectives and milestones for the 2-year effort are:

a) Demonstration of an HTS-scale FAR cooler meeting DoE Objectives
    a. Manufacture a 241-class FAR cooler (~300W @ 77K, for HTS-3)
    b. Map the performance of the 241-FAR cooler
    c. Place and test the 241-FAR cooler with an HTS user, if possible.
b) Demonstration of Reliability
    a. Perform Long-Term (5,000 hour minimum) Operating Test
    b. Measure Availability Factor, MTBF, Etc.
c) Extend FAR to cable-cooling capacity (HTS-4)
    a. Manufacture a 362-class cooler (~1000W @ 77K)
    b. Map the performance of the 362-FAR cooler

Success in this project will result in a commercially available cryocooler product suitable for HTS power systems. This is part of the Strategic Research arm of the DoE HTS program, which recognizes the need for such cryogenics to commercialize HTS and fulfills part of DoE's overall strategic themes #1 & 3 (Energy Security and Scientific Discovery & Innovation).

2008 Approach and Results:

This project follows a two-step approach of designing and building a 300W device (HTS-3) in Year 1; then applying lessons learned by extending that design to a 1,000W device (HTS-4); followed in Year 2 by construction and testing of the 1,000W unit in parallel with user-driven field test of the 300W unit. The 300W cooler represents a 30X increase in output from previously demonstrated coolers of this configuration and is an essential interim effort to assure the highest chance of success in the more commercially attractive 1,000W unit thereafter.

Accordingly, in Year 1, we have designed and built the 300W unit; verified its potential for attractive cost; and secured a beta test user (SuperPower). The 1,000W unit was also modeled and key parts designed (primary heat exchangers, coldtip vessel, etc.) for long-lead procurement. Procurement was also begun at-risk for other long-lead items in the 1,000W system, to minimize schedule risk in Year 2.

There were three notable technical challenges overcome in the first year, all related to practical fabrication of these large, high-frequency heat exchangers and flow guides. They were: the forming of the multiple, fine copper lots structure in the coldtip; the achievement of a helium-tight ambient heat exchanger (micro-tubular); and the development of a smooth-bore helium-tight flex line of large diameter. Each of these three is a novel element or process, and each is critical to the success of these coolers. Coldtip fabrication requires dozens of narrow, radial slots (less than 1 mm) deep and of varying depth, in a large, soft copper cold tip. Ambient exchanger requires hundreds of hermetic joints between small stainless tubes (1.0 mm ID) and end sheets and vessel. This success actually redeems a process developed under another DoE project in the 1980's, but not used since and reintroduced with new vendors here.

Last, the flex connector line that outwardly resembles the sort used on G-M cryocoolers must have a smooth bore, not the corrugated type used in G-M machines, to transmit the high-frequency, alternating-flow power (unlike the slow, unidirectional flow in conventional coolers). A smooth pipe would do it, but without the requisite flexibility that is the practical objective of this project. In experiments and commercial shipments of miniature versions, we had developed a smooth PTFE liner for a corrugated, helium-tight hose. However, it became clear in this year's work that at the larger diameters required for the HTS coolers, the PTFE is too stiff to flex and the end seals were separating under the stress. We developed a primary and a back-up that proved superior to the primary in both cost and function, combining reinforced silicone liner with special end fittings, to achieve a level of flexibility similar to the corrugated sheath hosing itself.

By the time of the Peer Review, we expect to have completed initial testing of the 300W unit (and may demonstrate it there). There are still risks inherent in the path from now (subassemblies) to then (complete build and performance-tested). These include potential hidden manufacturing flaws and delays, system modeling variance, and most seriously: internal flow disturbances not controlled or captured in modeling. All of these have been seen in various other first-build acoustic-Stirling coolers of different configurations, and the handling there is the first risk mitigation for this project. In addition, for the manufacturing flaws and delays, we have instituted a long-leads procurement process, purchasing as far ahead as these critical components can be defined. Our 300W coldhead was built and dry-fitted early according to this plan, identifying minor errors (mis-sized bolt circle, overlapping tolerances, etc.) in time for their correction to be done without overall program delay. The entire first year development (HTS-3 scale) is a risk mitigation for our Year 2 development at the still larger (3X more) HTS-4 (1000W) cooler.
The project has remained on budget and on time through the entire first year.

2009 Plans and Expectations:

Our Year 2 plans include complete testing and mapping of the HTS3 cooler; then lending it out to Beta-site testing at SuperPower (with support, if needed). In parallel, we will be building and testing the HTS 4 cooler at CFIC-Qdrive. Our overall goal is exiting the program with two running large-scale FAR coolers, each suitable for commercial HTS service.

There is some overlap planned for the in-house testing and user test of the 300W cooler. This is a flexible region of the schedule and will be driven largely by the user requirements and availability at SuperPower. Most of the Year 2 schedule is devoted to the construction, testing, and demonstration of the large cooler. We expect to invite potential users to CFIC-Qdrive for demonstrations of the large cooler when complete. Hardware demonstration of the 300W unit is a target (not certain) for the 2008 Peer Review meeting.

Technology Transfer, Collaboration, Partnerships:

In the first year, we have presented our theoretical treatment of the FAR connection to the International Cryocooler Conference; prosecuted the patent application for that invention (application published 2007 as 20070095074); agreed with SuperPower of Schenectady, NY to collaborate on long-term testing of the HTS-3 type FAR cooler in actual HTS duty outside our control; and presented the new technology to the US Navy Cryogenic Users' Customer Feedback Conference in Newport News, All reactions have been positive.

In addition, we have described this SBIR on our company website and have attracted several inquiries from potential users for similar equipment. We are presently building a special liquefier, to be a hybrid using our well-developed 2s362W pressure-wave generator (the driving base of the larger HTS4, 1000W year 2 cooler of this project), with a triplet of the 300W coldheads from this project's year 1. While more costly than the eventual single-head larger unit, this mitigates delivery risk and enables greater user exposure to the new technology at the earliest possible date. A similar configuration (3 year-1 heads on a single big driver) has also been ordered by the US Navy for use on-board aircraft carrier CVN78 (and successors).

Overall, this project is already attracting the interest and commitment of the larger cryogenics community, and that aids in rapidly establishing the reputation that will be required for utility commitment to HTS inrfrastructure applications. We anticipate success and thereby achieving most of the goals laid out in the DoE Cryogenics Roadmap for HTS use. Specifically, we expect to meet the reliability, capacity, weight, and cost (in volume) goals; in coolers sized to serve transformers or FCLs, and transmission lines.