# Hybrid Compressor/Expander Module

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*Subcontractors: Concepts NREC, White River Junction, VT; Scroll Corporation, Carlisle, MA*

## Objectives

- Based on the experience of two previous generations of scroll-based Compressor/Expander Modules developed with DOE, design and build a hybrid compressor/expander combining turbomachinery and positive displacement scroll compression.
- Deliver a system with equivalent thermodynamic performance, at significantly lower weight and volume, when compared to previous generations of scroll Compressor/Expander Modules.
- Develop the algorithms and hardware to ensure stable and effective control of the hybrid system.

## Technical Barriers

This project addresses the following technical barriers from the Fuel Cells section of the Hydrogen, Fuel Cells and Infrastructure Technologies Program Multi-Year R,D&D Plan:

- A. Compressors/Expanders

## Approach

- In the first phase, develop system architecture and subsystem designs consistent with the overall goals of maintaining thermodynamic performance while reducing weight and volume relative to previous generations.
- In the second phase, complete detailed engineering and initiate fabrication of brassboard and final subsystem components, and develop the control system hardware and algorithms.
- In the third and final phase, complete fabrication of components and conduct subsystem assembly and test, followed by system integration and performance verification.

## Accomplishments

- Completed detailed system design tradeoff study, resulting in specific definition of requirements for both the turbocompressor and scroll compressor subsystems.
- Completed detailed subsystem design tradeoff studies for turbocompressor and scroll compressor subsystems, resulting in selection of design configurations for both subsystems.
- Completed preliminary detailed design of both major subsystems, including component identification and sizing, cost estimation and performance estimates.

- Identified specific opportunities for performance enhancement through the use of limited exhaust gas recirculation.
- Initiated preliminary brassboard system testing of scroll compressor drive configuration to evaluate bearing performance and lubricant management.

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## Introduction

Most current automotive fuel cell systems are designed for pressurized operation in order to reduce system size, boost stack efficiency, and improve water management. Because of the aggressive efficiency goals driving fuel cell development, the compressor must operate efficiently over a wide flow range, and efficient waste energy recovery in an expander is required to offset the compression load. Traditionally, high-speed turbomachine technology, such as that used in automotive turbochargers, has resulted in a compact package that delivers high efficiency at the design point, but with performance that falls off dramatically under off-design conditions. Scroll technology, a type of positive displacement machinery, provides high compressor and expander efficiencies across a broad range of operating conditions, but results in a package that is significantly larger and heavier than that of high-speed centrifugal technology.

The objective of this project is to develop a hybrid compressor/expander module, based on both scroll and high-speed turbomachine technologies, which will combine the strengths of each technology to create a concept with superior performance at minimal size and cost. The resulting system will have efficiency and pressure delivery capability comparable to that of a scroll-only machine, at significantly reduced system size and weight when compared to scroll-only designs. In addition, this configuration offers the advantage of applying the required external power to the scroll compressor, a relatively low-speed device, eliminating the need for a high-speed motor to supply mechanical power to a turbomachine.

## Approach

The design approach for the Hybrid TurboScroll Compressor/Expander Module (CEM) exploits the experience of developing the first two generations of scroll Compressor/Expander Modules, in combination with the substantial experience of our turbomachine subcontractor, Concepts NREC. (Figure 1 shows the Second Generation Scroll CEM on its test stand). By combining the performance attributes of a positive displacement scroll compressor (electrically driven) with those of a turbocharger (driven by fuel cell exhaust gases), we expect to be able to very closely match the pressure/flow requirements of the DOE guidelines in a package that is smaller and lighter than previous generations. Figure 2 tabulates several key design goals for the project; they show dramatic improvement over the Second Generation performance noted.

A novel approach to the development of an appropriate system architecture resulted in the block diagram shown in Figure 3.In this configuration, the turbocompressor draws in atmospheric air and compresses it to an intermediate pressure. In order to reduce both the size and operating temperature of the scroll compressor, an intercooler is provided to reject part of the heat of compression to atmosphere. The partially compressed gas, now cooler and denser, is then fed into the scroll compressor, which uses electrical power to achieve the final compression of the gas. Finally, the compressed air is fed into the

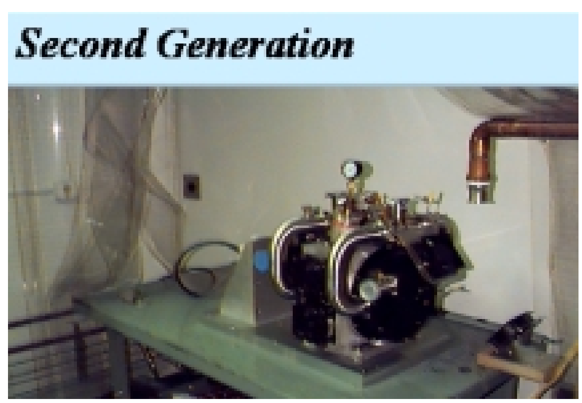


**Figure 1.** Second Generation Scroll Compressor/ Expander Module

fuel cell, which increases its temperature and reduces its pressure slightly. The exhaust gas from the fuel cell drives the turbine and, the bulk of its energy extracted, is exhausted to atmosphere. The turbine provides the shaft power to drive the turbocompressor by direct coupling. This operating mode is used up to a selectable fraction of maximum flow, currently set to approximately 80-90%, at which point a relief valve opens, permitting a small fraction of the discharge gas mass flow to bypass the turbine and be fed directly into the intercooler inlet. With this system feature, the turbomachine is dramatically simplified by eliminating the controllable inlet guide vanes, and its operating range is substantially reduced, thereby improving its overall efficiency profile.

This architecture offers some important advantages:

- The turbocompressor provides stack operating pressure control by purely passive means, eliminating the need for an active control element and its associated parts, actuator and control logic;
- The bypass valve permits recapture of a significant fraction of the discharge enthalpy without passing through the turbomachine;
- A fraction of the waste water in the discharge stream is recirculated into the inflow stream; and
- The scroll compressor provides pressure/flow characteristics that enable efficient operation across a broad range of flow rates.

Capturing these advantages entails, of necessity, overcoming certain risks:

- Overcoming a small oxygen deficit in the inflowing process gas that results from recirculating a small amount of discharge gas, and
- Managing any possible stack toxins in the discharge stream.

| Param. | Target | Hybrid | | | | 2nd Gen. CEM |
|---|---|---|---|---|---|---|
| | | Turbo | Scroll | Motor | Total | |
| Vol. (l) | 4 | 1 | 8 | 3 | 12 | 27 |
| Wgt. (lb) | 7 | 5 | 22 | 10 | 27 | 90 |
| Cost ($) | 200 | - | - | - | 300-340 | 355 |

**Figure 2.** Key Hybrid TurboScroll Performance

Starting with the turbocharger, pictured in Figure 4, the design approach involved balancing competing elements.; Over a dozen different turbomachine configurations were considered, exploring the potential for multiple stage and controllable geometry designs to address the performance requirements. Although ultimate performance can only be achieved with controllable guide vanes for the expander and/or compressor, these features add substantially to the cost and complexity of the turbomachine. By exploiting the opportunity to recirculate a small fraction of the discharge gas, a fixed geometry turbomachine can be made to cover the full required performance range. For the scroll, the design approach has involved the detailed evaluation of three competing configuration options and the selection of a single conventional design approach, as shown in Figure 5. This design represents a low-risk approach, incorporating new and stringent lubricant management features into well-proven design configurations. A brassboard working model of the drive mechanism currently under construction will prove the utility and functionality of the preliminary design.

## Results

A novel system architecture has been developed that exploits a simple pressure-operated relief valve to permit a fixed-geometry turbine to provide stack

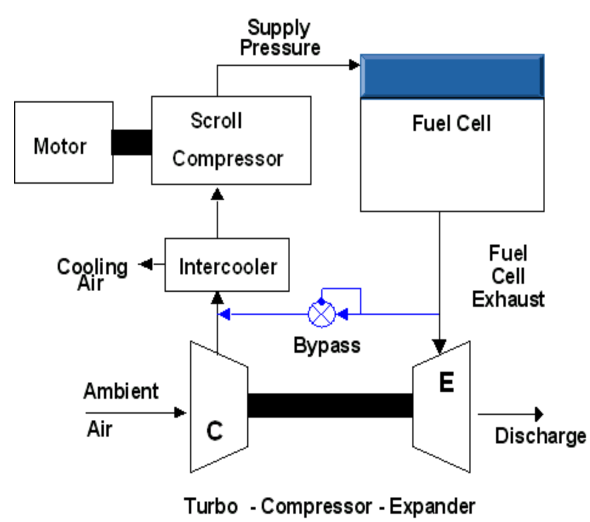


**Figure 3.** Hybrid TurboScroll System Architecture

pressure control tailorable to a wide variety of possible pressure-flow profiles. The system feeds both the turbocompressor output and any bypass gas into an intercooler for rejection of heat and densification of the process gas prior to compression to final operating pressure through the scroll compressor. Based on detailed preliminary designs, substantial improvements in system weight and volume, relative to previous generation machines, have been achieved by the hybridization of turbo-compression and positive displacement scroll compression in this system. Manufacturing costs based on these preliminary designs have also improved.

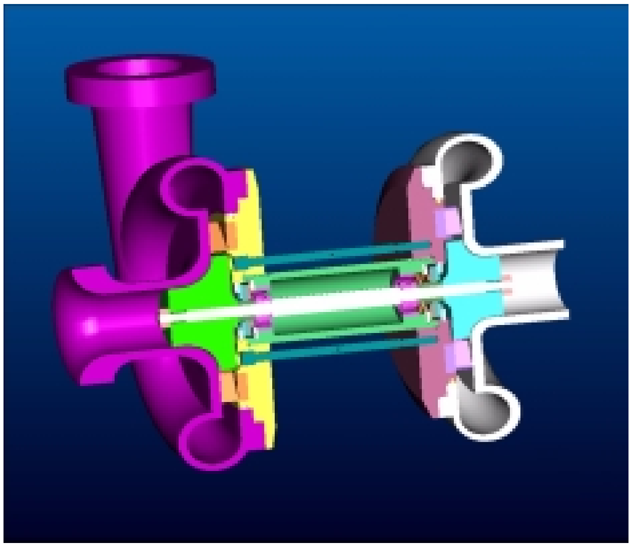

**Figure 4.** TurboCompressor Preliminary Design

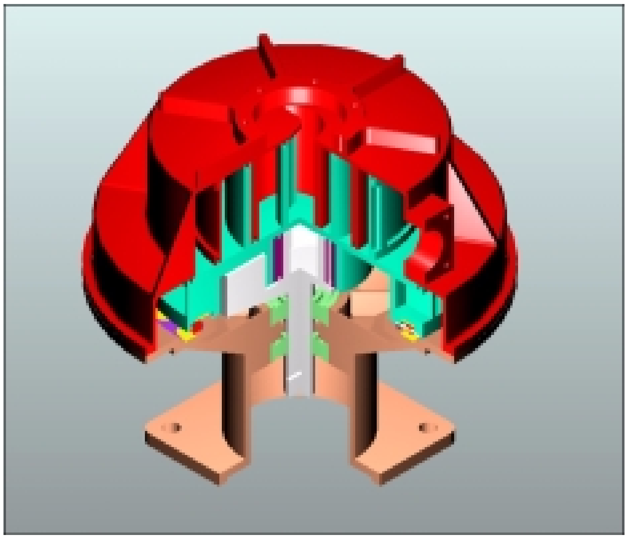

**Figure 5.** Scroll Compressor Preliminary Design

Preliminary design of the turbocompressor has been completed. In the turbocompressor, conventional grease-lubricated ball bearings have been identified and selected. Lubricant management is simplified by the relatively low vapor pressure of the selected grease, as well as the physical and pressure-gradient isolation provided in the design of the turbocompressor. Aluminum wheels and housings have been designed, and the rotordynamics configured to provide "stiff," or below-resonance, operation over the whole operating range. Estimated maximum turbine efficiencies of 86%, and compressor efficiencies up to 75%, closely approach the targets defined in the DOE guidelines. The intercooler has conventional performance requirements, and, indeed, the selected approach is to use an available automotive intercooler of the appropriate size and integrate it into the system.

Preliminary design of the scroll compressor has been completed. The selected scroll compressor design uses a conventional crank-driven orbiting scroll, supported on a roller-Oldham thrust bearing system, grease lubricated. This configuration has the substantial advantage of conventionality, enabling the direct utilization of knowledge gained in dozens of scroll compressor design programs. The most highly stressed machine element, the crank bearing, has been selected and will be tested in a full-scale brassboard drive mechanism demonstration device. This roller bearing will be of conventional design and grease lubricated. The lubricant for both the crank and thrust bearings will be isolated from the process gas by three means: (1) the high viscosity and low volatility of the grease itself, (2) mechanical sealing of the process gas space from the lubricant space, and (3) pressure gradient isolation of any tramp lubricant from entering the process stream. Estimated compressor peak efficiencies of 70% are comparable with the efficiencies demonstrated in previous generations of scroll compressors and indicate that the overall net shaft power consumption of the system will be approximately 5-6 kW.

## Conclusions

Based on detailed preliminary designs of the critical system elements, the Hybrid TurboScroll Compressor/Expander Module concept will deliver significant improvements in weight, volume and manufacturing cost relative to previous generation systems. Further, based on analysis of the preliminary designs, the parasitic power requirements of the system are also expected to improve. A novel system architecture substantially simplifies the overall system, permits flexible pressure/flow tailoring of the system behavior, and provides important improvements in manufacturability with minimal performance penalty provided that the small decrease in oxygen concentration in the feed gas is well tolerated by the fuel cell.

## FY 2003 Publications/Presentations

1. DOE Compressor/Expander Module Development Program, Tech Team Meeting, April 16, 2003.
2. DOE Compressor/Expander Module Development Program, Merit Review Meeting, May 22, 2003.