# Motor Blower Technologies for Fuel Cell Automotive Power Systems

*Thomas Clark (Primary Contact), Michael Arner*
*UTC Fuel Cells (UTCFC)*
*195 Governors Highway*
*South Windsor, CT 06074*
*Phone: (860) 727-2287; Fax: (860) 727-2319; E-mail: tom.clark@utcfuelcells.com*

*DOE Technology Development Manager: John A. Garbak*
*Phone: (202) 586-1723; Fax: (202) 586-9811; E-mail: John.Garbak@ee.doe.gov*

*Subcontractors: Phoenix Analysis and Design Technologies, Phoenix, AZ; R&D Dynamics, Bloomfield, CT*

## Objectives

- Develop small, lightweight, motor driven blowers to provide cathode air and reformer air for a near ambient fuel cell operating on gasoline.
- Identify and/or develop manufacturing methods that will allow the blowers to be produced at low cost in large production volumes.
- Demonstrate blower performance via integration into a power plant.
- Evaluate both reformer air blower approaches, regenerative vs. centrifugal, and identify superior technology.

## 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

- Define performance requirements, flows, pressures, temperatures as well as cost and life targets for an ambient pressure based fuel cell system.
- Phoenix Analysis and Design Technologies (PADT) will develop and build a mixed flow type blower to meet requirements for cathode air and a regenerative type blower to meet reformer air requirements. Prototypes will be used to evaluate aerodynamic performance as well as life and durability.
- R&D Dynamics will develop and build a high-speed centrifugal machine supported by air bearings as an alternate approach to the reformer air application.
- UTC Fuel Cells will demonstrate operability and performance of both approaches by integrating the units into a power plant or conducting subsystem testing.

## Accomplishments

- Requirements for both the cathode air blower and reformer air blower have been defined and documented.
- PADT has tested the mixed flow cathode air machine to 100% design speed and achieved greater than 60% overall efficiency at rated flow and pressure rise.

- The R&D Dynamics high-speed compressor was down-selected as the preferred reformer air blower over the PADT proposed regenerative machine.
- R&D Dynamics has tested the high-speed centrifugal machine to 85% of design speed. Demonstrated flow and pressure maps agree well with the predicted values, and a peak overall efficiency of 50% has been demonstrated.
- PADT has completed a cost study which predicts production costs of $83 per blower in quantities of 100,000 units/year.

### Future Directions

- Continue testing of R&D Dynamics compressor to 100% of design speed.
- Deliver both blowers to UTC Fuel Cells for evaluation in subsystems.
- Continue off-design testing to evaluate robustness of designs under high ambient and process inlet temperature conditions.
- Continue to refine designs for low cost manufacturing processes and ease of assembly.
- Investigate lower cost motor and motor drive technologies.

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## Introduction

Near ambient pressure fuel cells running on gasoline require two sources of air, one for the fuel cell cathode and one for the gasoline reformer, which generates hydrogen. Due to the relative pressure differences required by the two applications, it is not energy efficient to fulfill the two air requirements with a single blower/compressor as is commonly utilized in pressurized type fuel cell systems. This project will develop two different types of machines to meet each air supply requirement independently.

Blowers to meet these two applications are not commercially available in the size and volume required for packaging into a vehicle. Thus, this project aims to utilize high speed technology which will allow the blowers to develop the required flow and pressure rise in a small package size. Increasing the rotational speed presents several technical challenges, namely bearing life and motor heating. The motor heating issue is further compounded by the fact that we are able to reduce the size of the motor by running at higher speeds, yet the amount of shaft power required to be output by the motor remains the same. This results in a much higher than typical power density motor, and with the reduction in surface area, a much higher heat flux is required to maintain stator temperatures. This problem can be resolved in one of two ways: increase the efficiency of the motor and reduce the amount of heat generated by it, or increase the heat transfer capability of the stator and motor housing.

## Approach

The approach for this project was to first define and document the blower requirements for an ambient pressure fuel cell system. The requirements issued by DOE in 2000 focused on targets for pressurized systems that were not directly applicable to the UTCFC ambient pressure system. New targets for blower performance, efficiency, cost, weight and volume were defined by UTCFC and documented in 2001, and the air flow requirements were separated into two distinct applications: the cathode air blower, a high flow low pressure application, and the reformer air blower, a higher pressure low flow type application.

Using these requirements for the two applications mentioned above, we identified three types of machines with possible benefits to the two applications, one for the cathode air blower and two types for the reformer air blower. The types of machines considered were restricted to what could be classified as mature air moving technology and thus would allow us to focus on reducing size, weight and cost rather than doing fundamental aerodynamic development. For the cathode air blower application, a mixed flow axial machine was selected. The aerodynamics for these types of machines are well understood; thus, we were able to limit our scope of aerodynamic development to minor variations of the basic design to achieve optimum efficiency.

For the reformer air blower, we considered two types of machines, each with its own unique set of advantages. The first machine was a very high speed, 140,000 rpm, radial centrifugal machine supported by air bearings. Because of the high speed, this type of machine is capable of delivering high pressure air in a very small package size with good overall efficiency. However, the very high speeds also required some technology development to minimize risks associated with the bearings and very high-speed motors and controllers. Thus, a regenerative type machine was evaluated as a potential second reformer air blower technology. Regenerative type machines are typically very good at developing higher pressures at low flow rates and lower speeds than typical centrifugal devices, which makes this technology attractive. The flow and pressure could be developed at speeds consistent with the use of grease packed ball bearings, which are desirable due to their low cost. However, regenerative type machines are typically lower efficiency as compared to other centrifugal machines; thus, a key task was to perform basic aerodynamic research into variations of the traditional regenerative wheel and housing design to optimize for peak efficiency.

## Results

The cathode air blower and controller designs have been completed and are shown in Figures 1 and 2. The blower and motor drive have been tested to 100% of design speed, and performance is shown in Figure 3. Please note that efficiency shown in this figure is overall efficiency and accounts for all losses in the motor/motor drive and all frictional losses and is a true representation of the total parasitic load to the fuel cell system associated with providing cathode air. It is calculated by dividing the isentropic power by the direct current power input to the motor drive.

The blower has been designed for low cost, high volume production, and several of the parts used in the prototype blowers were actually manufactured using injection molding techniques which will yield very low per piece cost in production volumes. Additionally, much of the effort this year focused on reducing effort and precision required to assemble the components, thereby reducing the cost associated with final assembly of the blower. A detailed cost study was conducted for each part of the blower and the final assembly effort, during which manufacturers were asked to quote production prices in volumes of 100,000 per year. A total cost for the blower and motor drive of $83 is predicted, which compares favorably with our initial cost target of $75 per blower.

The high-speed reformer air blower and controller, developed by R&D Dynamics, are shown

**Figure 1.** PADT Cathode Air Blower

**Figure 2.** PADT Cathode Air Blower Controller

in Figures 4 and 5, respectively. At the time of this writing, they have been tested to 120,000 rpm. Approximately 85% of design speed and performance, as shown in Figure 6, is inline with predicted values. Unfortunately, rotor heating and motor controller issues have prevented us from running to 100% of design speed thus far. This past year was heavily focused on reducing the severity of motor rotor heating effects with solutions concentrated in two areas: 1) increasing the amount of cooling air supplied to the motor cavity and 2) experimenting with rotor magnets and rotor materials to reduce heating caused by eddy current losses. A new motor cooling scheme that taps into process air from the blower exit, rejects heat through finned tubing and directs it through the motor cavity has shown good results and enabled us to achieve 120,000 rpm. We believe this technique will allow us to reach 100% design speed. In addition to improving the current motor and controller designs, we have purchased a new motor and controller which have been designed from the ground up to minimize rotor heating due to eddy currents. We expect that these new motor and controller designs will allow us to run speeds in excess of 100% design speed, and combined with the improved cooling scheme, should give us acceptable thermal margins even with elevated blower inlet air temperatures.

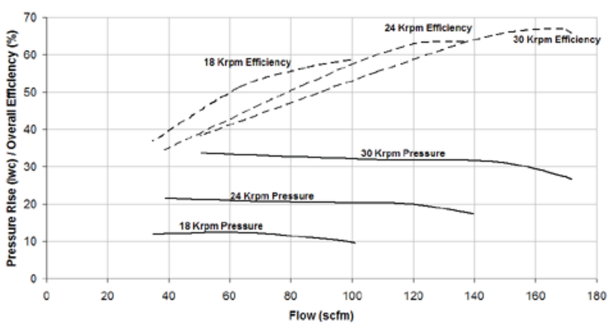


**Figure 3.** PADT Cathode Air Blower Performance (iwc = inches water column)

**Figure 4.** R&D Dynamics Reformer Air Blower

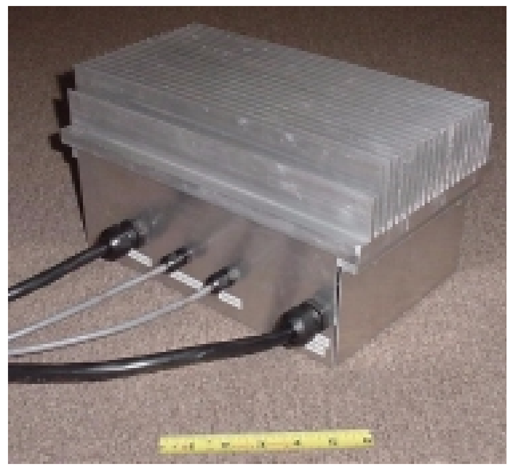

**Figure 5.** R&D Dynamics Reformer Air Blower Controller

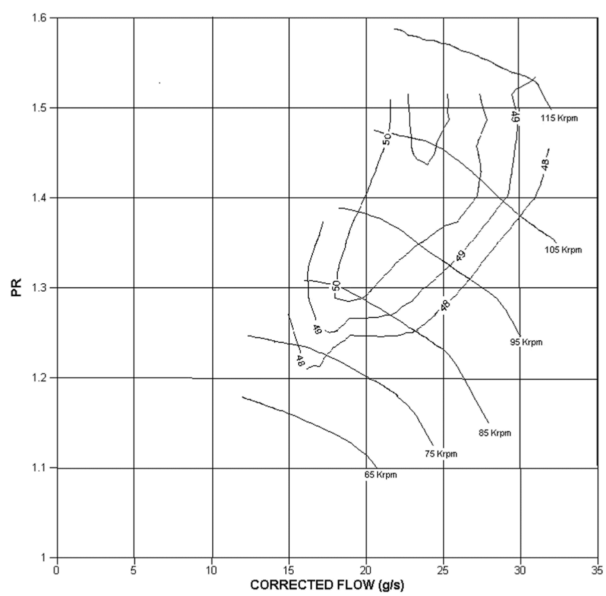


**Figure 6.** R&D Dynamics Reformer Air Blower Performance (PR = pressure ratio)

The regenerative technology reformer air blower development effort has not produced the results we had hoped for and the aforementioned task to achieve significantly improved aerodynamic efficiencies. To assist us in this task, a fluidic model was developed and calibrated with actual test data and has allowed us to easily and accurately predict wheel efficiencies for a variety of wheel configurations. Unfortunately, the model has shown that the traditional regenerative wheel design is very difficult to improve upon, as numerous wheel design variations were modeled and the best one increased pump head efficiency by only 2 percentage points over the traditional design. As a result of this inherently low wheel efficiency, the increased shaft power required from the motor resulted in a severe heating problem for both the motor and pump head in addition to low overall efficiency. For this reason, we have decided to terminate the regenerative blower effort and redirect our efforts to more meaningful technical challenges in other areas within the program.

## Conclusions

- The cathode air blower is a very efficient way to move air at low pressure ratios. Work in the coming year will focus primarily on increasing blower reliability and durability in high temperature and high vibration applications.
- The high-speed, centrifugal reformer air blower design has produced predicted aerodynamic performance in a very compact package. Future work will focus on the achievement of 100% design speed, redesigning the unit for low cost, high volume production and achieving motor controller durability.
- When working with compact, high-speed motors, the number one issue is motor rotor heating. The motor controller and motor rotor must be designed as a package to minimize this effect.
- Regenerative type machines are inherently inefficient and are best suited for applications requiring a pressure ratio less than 1.3.

## FY 2003 Publications/Presentations

1. Freedom Car Annual Review, April 16, 2003, Detroit, MI
2. DOE Merit Review, May 22, 2003, Berkeley, CA