

# 2005 DOE Hydrogen Program Fuel Cell APU

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Project ID #  
FCP32

# Overview

## Timeline

- Project start date 03/01/2004
- Project end date 06/31/06
- Percent complete – 60%

## Budget

- Total project funding
  - DOE share \$360,000
  - Contractor share \$0
- Funding received in FY04 \$300,000
- Funding for FY05 \$60,000

## Barriers

- Barriers addressed
  - A. Lack of SOFC
  - B. Design of DC/DC Converter
  - C. Hybrid power system

## Partners

- Chevron/Texaco
- Carrier/Transicold

# Objectives

- Characterize the emissions, power requirements, and operating conditions of the TRU, Trailer Refrigeration Units, in the United States. **Finished**
- Demonstrate the use of a fuel cell APU as a power source for a TRU. The demonstration is to be carried out in the field. 60% finished.
- Original plan was to purchase a SOFC, however we have built a PEM APU. 90%

# A Typical TRU System in the Field

Refrigeration Unit

Diesel Engine

Trailer



# TRU Field Testing



Emissions sampler with exhaust system of the box truck TRU.



Emissions sampler as seen from the top of the large trailer unit.

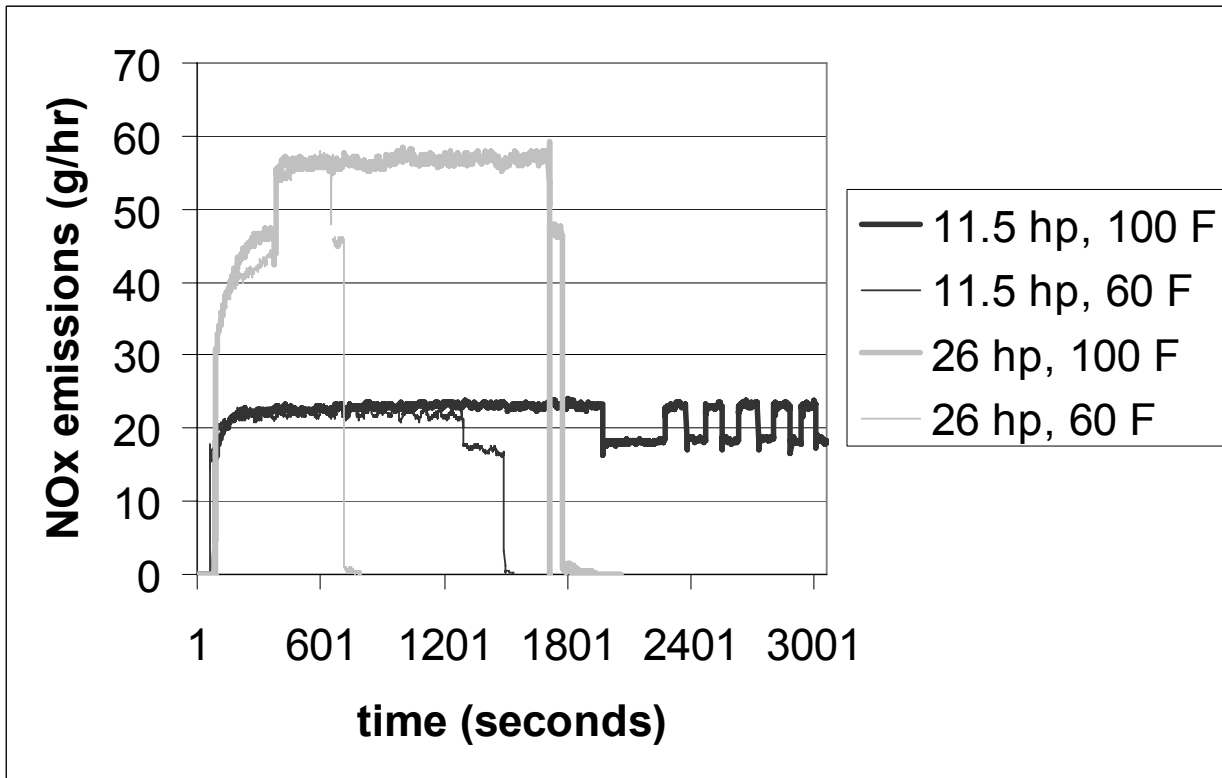
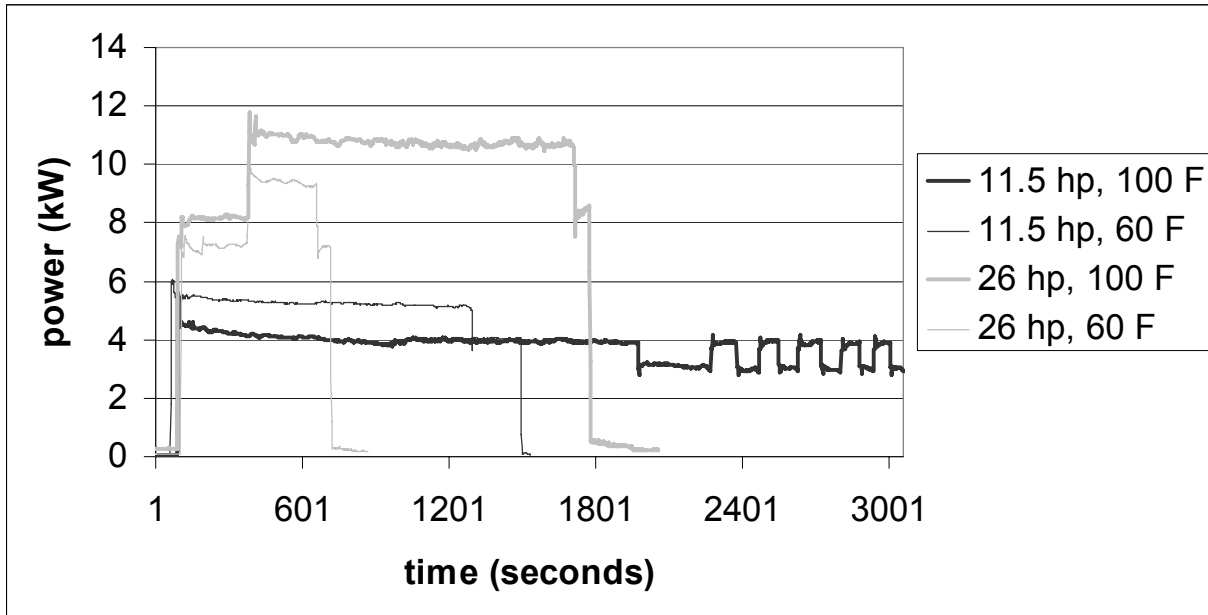
**Table 1.** Population distribution of TRUs in California (ARB, 2003).

<b>Horsepower</b>	<b>Number</b>
<b>&lt;15 hp</b>	<b>4600</b>
<b>15-25 hp</b>	<b>1900</b>
<b>25-50 hp</b>	<b>22800</b>
<b>25-50 hp (out of state)</b>	<b>7500</b>
<b>25-50 hp (rail)</b>	<b>1700</b>
<b>&gt;50 hp</b>	<b>0</b>
<b>TOTAL</b>	<b>38500</b>

**Table 2.** Cost and volume based on TRU size.

	<b>hp rating</b>			
		<b>Cost</b>	<b>Volume (L)</b>	<b>Weight (kg)</b>
<b>Trucks with TRU</b>	<b>&lt;15</b>	<b>\$15,000</b>	<b>1200</b>	<b>500</b>
	<b>15-25</b>	<b>\$20,000</b>	<b>1500</b>	<b>550</b>
	<b>25-50</b>	<b>\$23,000</b>	<b>~2100</b>	<b>730</b>

# Typical Results from TRU Field Testing



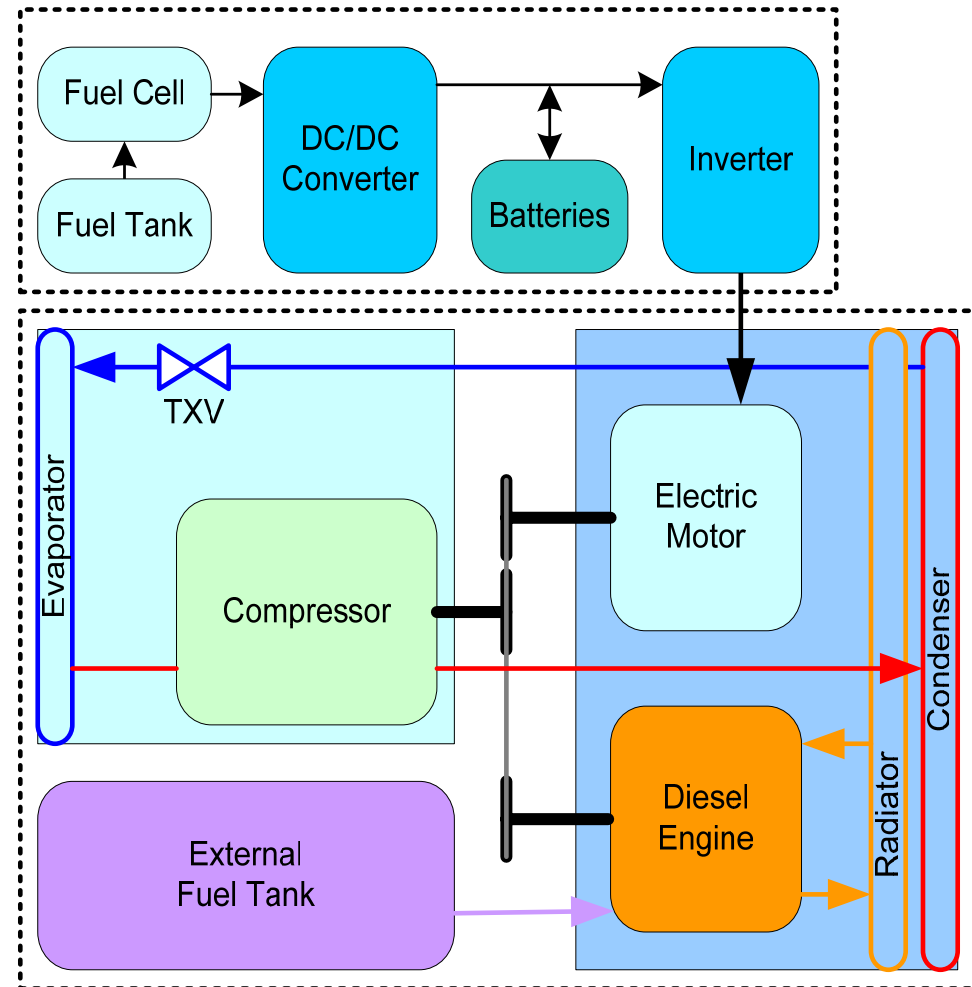
# CONCLUSIONS of TRU Testing

1. Average operations, emissions, and fuel consumption were presented for 10 replications of each of four test combinations: large TRU in colder weather, large TRU in hot weather, small TRU in colder weather, small TRU in hot weather.
2. Initial operations for all tests were at full power, high speed. The amount of time spent in each mode generally depended upon factors such as the cargo, the amount of opening the doors, the insulation of the trailer, the initial temperature of the trailer, and the ambient temperature.
3. Once the TRU engine warmed up, the ambient temperature had a small effect on the g NO<sub>x</sub>/hr emissions of either TRU. The medium and large units produced 23 g/hr and 57 g/hr NO<sub>x</sub>, respectively in both the hot and cold ambient conditions.
4. In terms of grams per power per hour, the units commonly used for emissions models, the emissions from the two TRUs were similar. For the medium units 3.8 g/kW-hr and 5.8 g/kW-hr of NO<sub>x</sub> were emitted the cold and hot ambient conditions, respectively.
5. For the smaller TRU, the hot operating conditions had nearly a 50% increase in NO<sub>x</sub> emissions. For the larger TRU, the NO<sub>x</sub> emission in the hotter conditions were approximately 15% lower than in the cooler conditions.
6. NO<sub>x</sub> emissions measured in this study were much lower than those estimated by CARB's emissions inventory process.

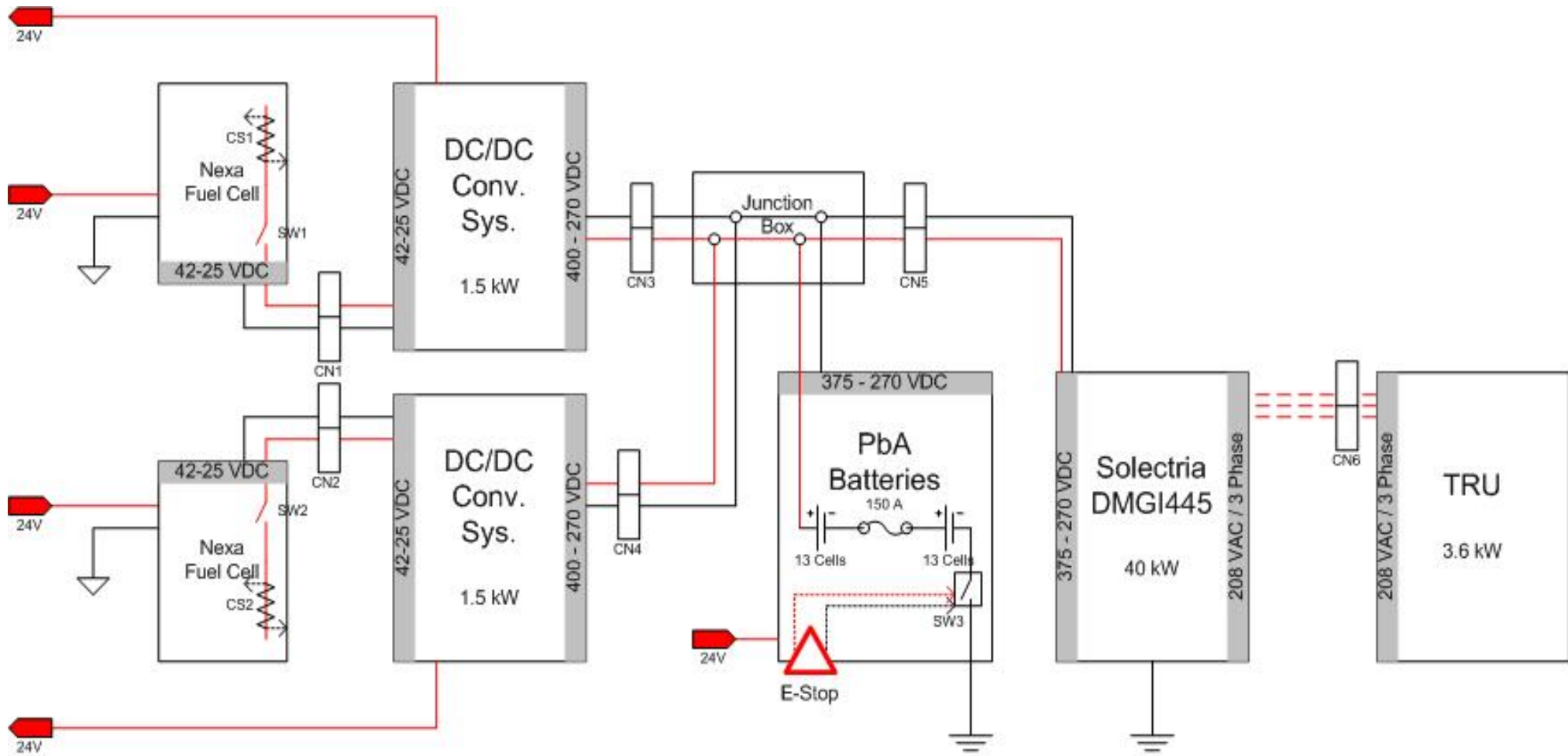


# Block Diagram of Hybrid PEM APU for TRU

- Fuel Cell Unit
  - Fuel Cell
  - H2 Fuel Storage
  - DC/DC Converter
  - Batteries
  - Inverter
- TRU
  - Electric Motor
  - Diesel Engine
  - Compressor
  - Heat Exchangers
  - Fuel Tank



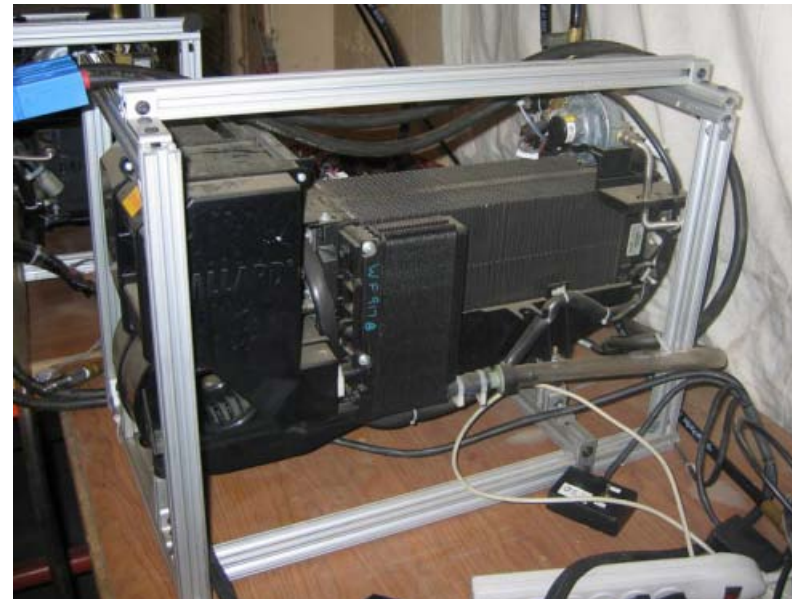
# System Overview



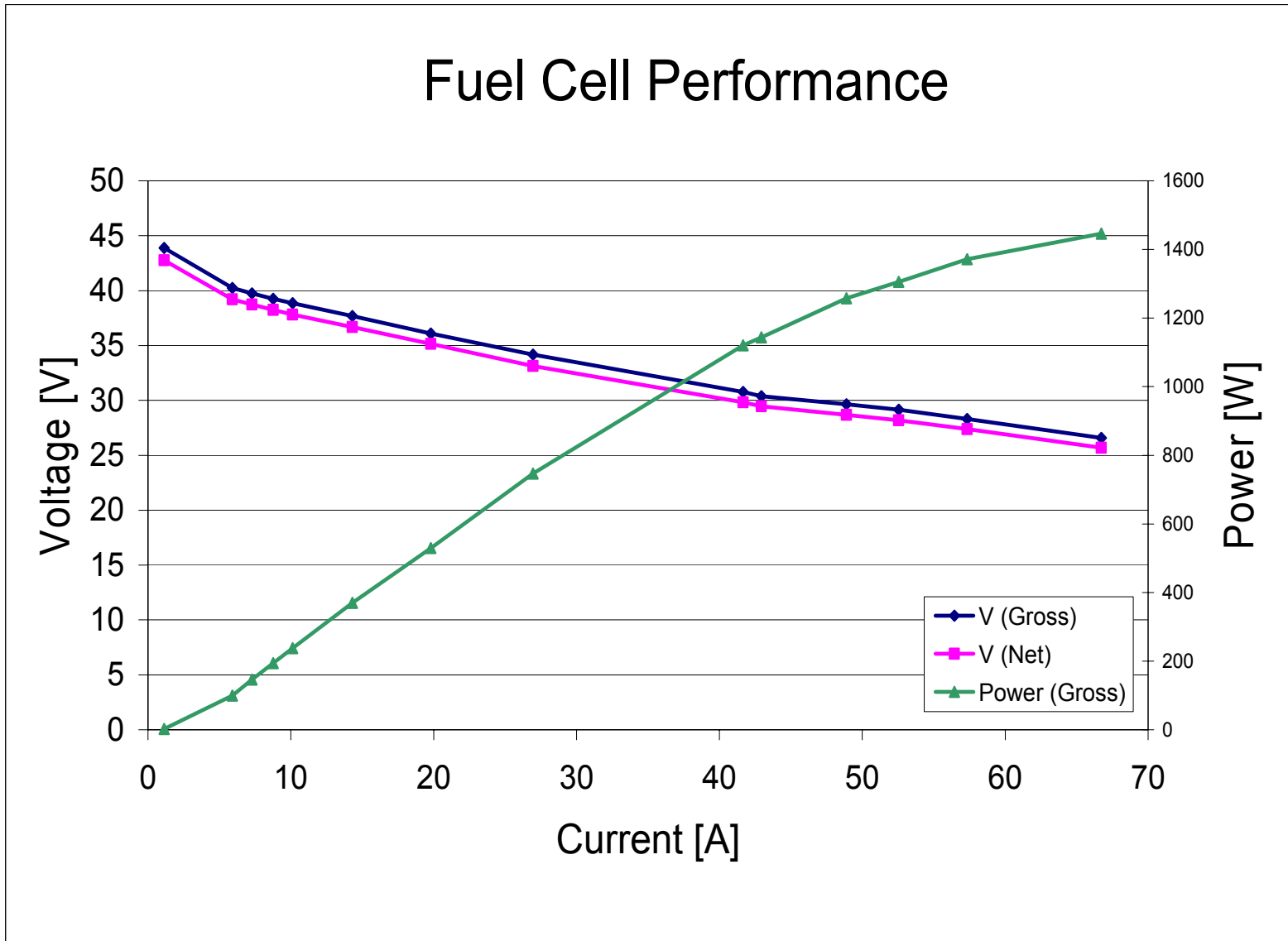
# PEM Fuel Cell

- Ballard Nexa PEM FC
  - 1.2 kW Rated Output
  - 42 – 25 VDC Output

Ballard Nexa PEM Fuel Cell		
Outputs		
Rated Power	1200	W
Rated Voltage	26	V
Mass	13	kg
Operating Life	1500	hrs
Inputs		
Fuel	99.99%	Hydrogen
Consumption	<18.5	SLPM
DC Startup Power	18 - 30	V

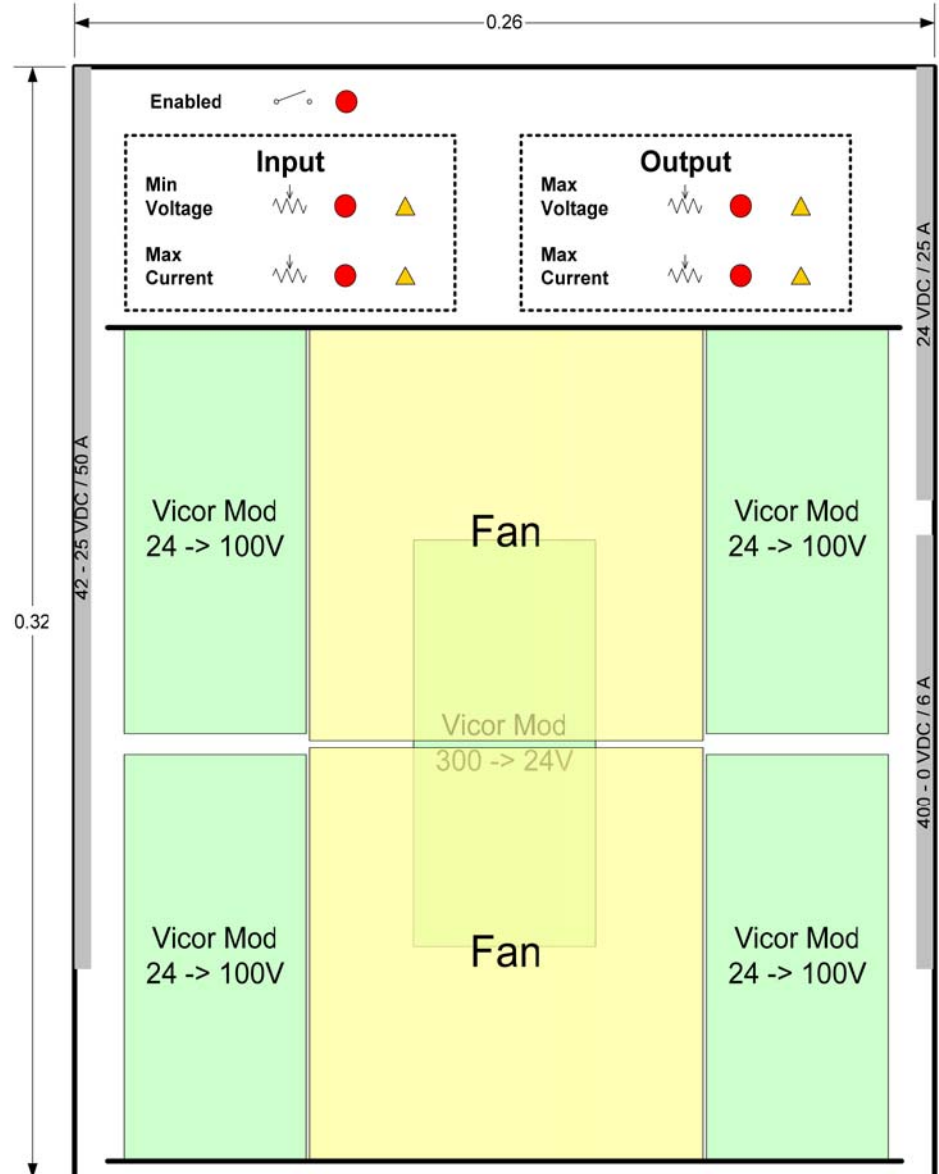


# Nexa Performance



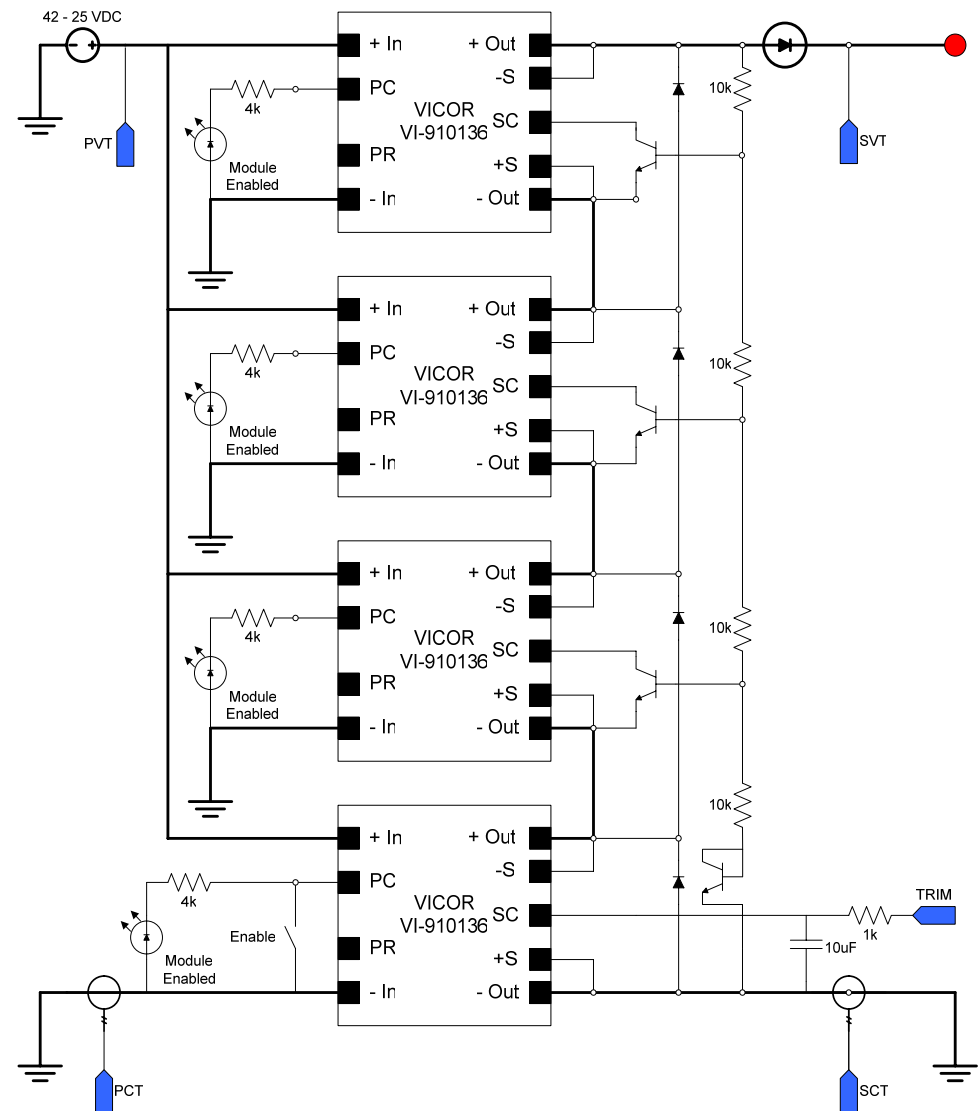
# DC/DC Converter

- Physical Design
  - Heat Sink Enclosure Assembly
    - Heat Sink
    - Fans
  - Panel Controls
    - On/Off Power Switch
    - Voltage and Current Limit Pots
    - Test Taps



# DC/DC Converter

- Custom Built for application
- General Function
  - Control Circuit
    - Input Min Voltage
    - Input Max Current
    - Output Max Voltage
    - Output Max Current
- Electronic Design
  - Utilizes special order Vicor DC/DC converter modules
  - Ladder Circuit
    - Necessary to trim each module simultaneously



# Battery Box

- Hawker Odyssey
  - 26 Battery Series String
    - 26Ah Cells
    - 10.8 kg / battery
    - ~ 6.5 kW-hr @ C/1
  - Voltages
    - > 275 V Loaded
    - 322 V Nominal
    - 359 V Float



# DC/AC Inverter

- Solectria DMGI 445
  - 14.9 kg
  - 260 – 400VDC Input
  - 3 Phase 208VAC  
Output identical to grid power
    - 40kW Peak Output
    - Programmed for “soft start”
    - Frequency and voltage ramp up





# Transport Refrigeration Unit

- Carrier Supra 544
  - Capacity
    - 3080W @ -20C
    - 5425W @ 0C
  - Kubota 2 cylinder 480cc Diesel Engine
  - 3.6 kW Standby Electric Motor



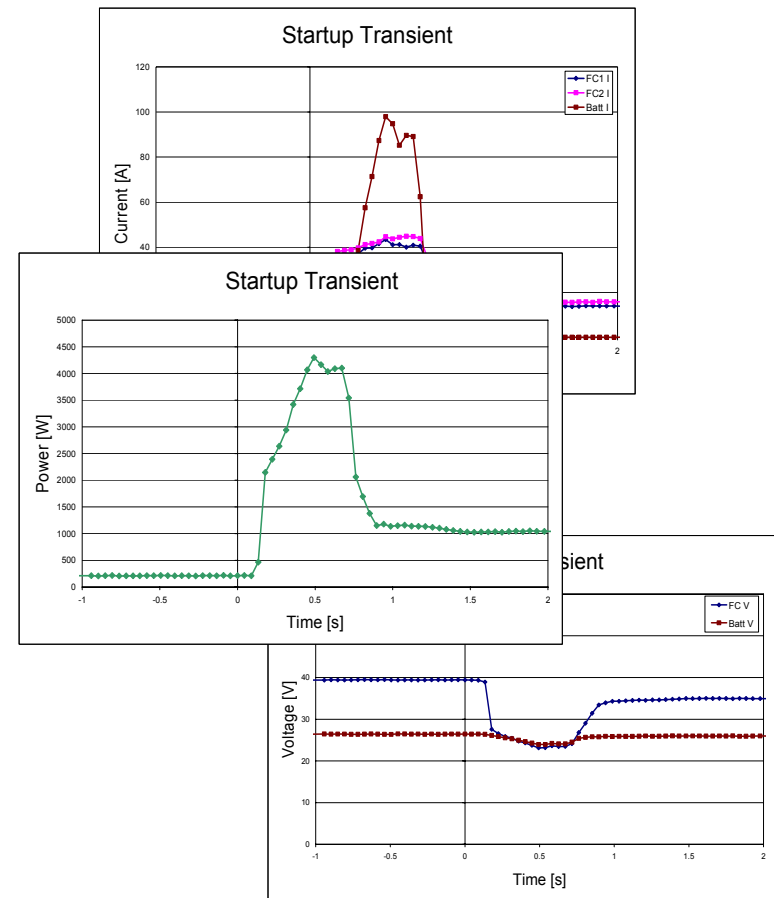
# Bench Testing Plan

- Bench Testing
  - Setup instrumentation
    - Current and voltage measurement points
      - DC/DC Converter Output (2)
      - Battery Box Output
      - Fuel Cell Output
  - Transient testing
    - On/Off of TRU
  - Steady state testing
    - Various temperatures



# Bench and Demo Testing

- Demonstration / Testing
  - Perform Bench Testing
  - Find partner company to do demonstration TRU testing



# Future Tasks Outline

January	February	March	April	May	June
Complete Assembly of Bench Test			Thesis Writing		
		Bench Testing		Publish Results	
			Trailer Installation		
			Demonstration / Testing		

- Assemble Bench Test
  - DC/DC Converter
  - Battery Box
  - Fuel Cells
  - Junction Box
  - AC Inverter

- Bench Testing
  - Instrument Unit
  - Perform Tests
- Trailer Installation
  - Purchase trailer
  - Design for safety
  - Install components
- Demonstration / Testing
  - Find partner company to do TRU testing with

# Trailer Demonstration

- Trailer Installation
  - Purchase trailer
  - Design for safety
    - Passive and active venting
    - H2 Sensor
- Install components
- Demonstrate
- Publish Results



# System Advantages

Our Hybrid System Design has the following advantages

- Undersized Fuel Cells can be used for large power applications
- Batteries can be charged at maximum efficiency point of the fuel cells
- The further development of Li/ion batteries will solve the present problem of system weight
- Future developments of scroll compressors unit will allow for the refrigeration system to be driven by DC motors. This has the potential to increase the efficiency of the cooling process.

## **Important Note for our Program:**

At one time in our planning for this research project we had hoped to purchase or receive as a gift a SOFC, solid oxide fuel cell. Although we have spent countless days in discussions, and we have been promised a delivery of a SOFC, it does not appear that the SOFC will arrive in a timely fashion. At the present time we have a delivery date of January, 2006, however we do not have any detailed information or specifications for this fuel cell. Even if the SOFC arrives in January, of 2006, it will take months to test and document the performance of the SOFC. Also, it will take a considerable amount of time to integrate the new SOFC into a portable system to power a TRU.

The final point that should be made is that UC Davis has built a hybrid fuel cell APU system to power a TRU. It was not originally planned to purchase the APU system from ITS Davis, however the realities of the SOFC fuel cell industry has caused us to build our own system. This team was fortunate to be about to use the infrastructure of ITS Davis to build this system, and this has lead to the success that we have had.

## Review of Progress

During this latest phase of our contract we have built a hybrid fuel cell power system to power a Trailer Refrigeration Unit, TRU. At the present time we are testing the equipment and we are in the process of assembling the parts needed to carry out a demonstrating on a TRU that is powered by our hybrid fuel cell system. The four major components of our system are the following:

1. A TRU system has been delivered and tested, and this TRU is capable of being powered by both a diesel engine and an electrical motor.
2. A fuel cell power system has been built and tested to supply electricity to the TRU through a hybrid power supply system.
3. A power electronics package has been built and tested, and this electronics package supplies the 3 phase and 240 volt power needed by the TRU electrical motor.
4. A hybrid battery storage system has been built and tested, and this storage system was needed to increase the power supply level of the fuel cells.