IDATECH
An IDACORP Company
Advanced Fuel Cell Solutions™

Research & Development for Off-Road Fuel Cell Applications

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4/12/05

FC43 Steinbroner

Overview

Timeline

- Project start date 12/01/04
- Project end date 12/31/07
- Percent complete 7%

Barriers

- Barriers addressed
  - P. Durability

Budget

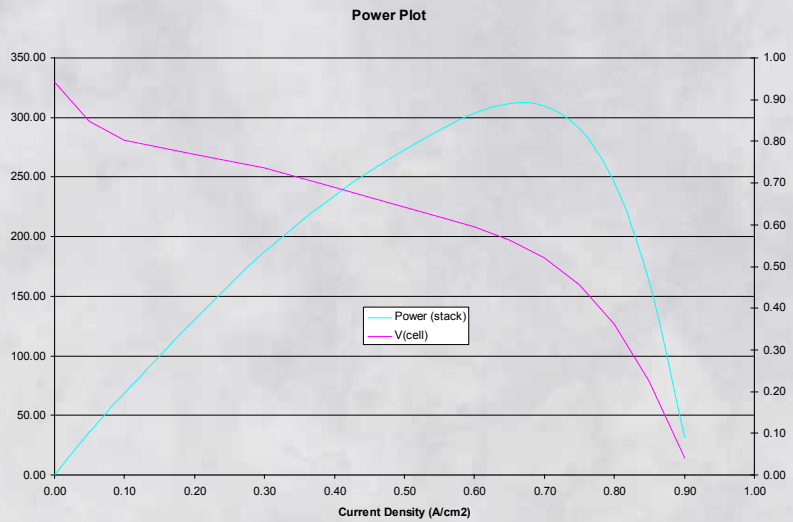
- Total project funding
  - DOE share $ 418,912
  - Contractor share $1,001,475
- Funding received in FY04
  - $ 50,000
- Funding for FY05
  - $ 418,619

Partners

- IdaTech, LLC
- The Toro Company
- Donaldson
- UC Davis

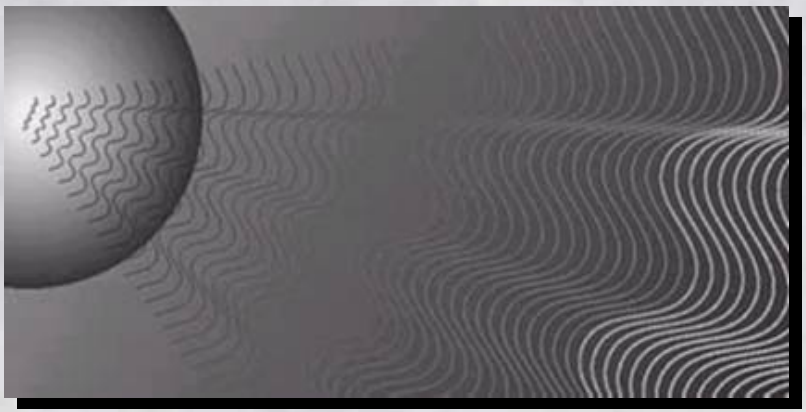
Objectives - 2005

- **Task 1: System Study**
  - Identify off road vehicle conditions, as pertains to fuel cell system power production and utilization
    - Including:
      - Load profiles
      - Drive train, PTO, actuators, etc.
      - Force & speed
      - Acceleration



Objectives - 2005

- **Task 2: Impulse & Vibration Study**
  - Utilize existing information to generate profiles for typical impulse and vibration forces on the off road vehicle
    - Equip Toro electric vehicle with accelerometers



Objectives - 2005

- **Task 3: Air Quality Study**
  - Develop a database of possible environmental contaminants that could effect the operation of the fuel cell system (cathode contamination)
  - Construct single cell fuel cell test systems to evaluate the effects of air contaminants on the cathode side of the fuel cell

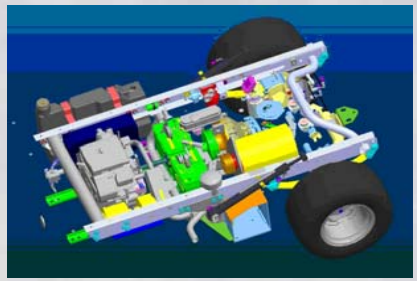
- **Task 4: Fuel Cell Specification**
  - No work defined for this year

Objectives by contractor

- Report on Load Profiles & Lifetime — **Lead:** UC Davis, **Support**: Toro
- Air Filtration Project Report — **Lead:** Donaldson, **Support:** IdaTech, UC Davis
- Impulse & Vibration Project Report — **Lead:** Donaldson, **Support:** IdaTech
- PEM Fuel Cell System Specification — **Lead:** Toro, **Support:** UC Davis
- Final Report — **Full Team Responsibility**
- Actively communicate results in public forums and distributed media in support of DOE's communications program.

Approach

- This program will utilize both existing and experimental data to generate information pertaining to the operation of a fuel cell system in an off-road environment. Specifically the program will address and identify:
  - Load profiles for an all electric Toro Workman
  - Load profiles for existing off road equipment (tractors, mowers, etc…)
  - Impulse and vibration information for existing off road equipment, as well as for a experimental data from a Toro Workman
  - Cathode contaminants that are "typical" in an off road environment
  - Fuel cell test apparatus that will identify the effects of the contaminants on the operation of a Fuel cell system
  - Design of mitigation for impulse, vibration, and air contaminants
  - Testing of the mitigation strategies



Technical Accomplishments: Task 1: System Study

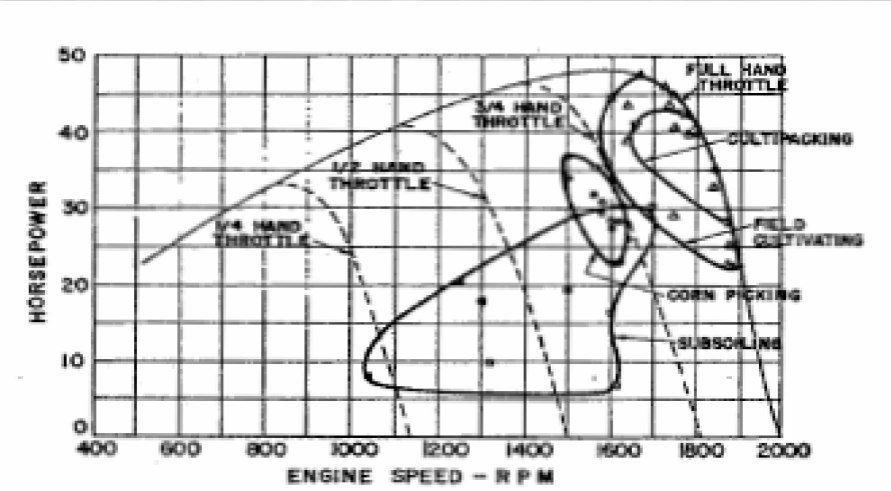
- Identification of a variety of load profiles for off road vehicles (agricultural tractors) has been accomplished, including:
  - Engine power and torque, PTO (Power Take Off), and Drawbar power (the power required to pull an implement at a uniform speed).

Table 1: Power take-off torsional loads[7]

TEST NO.	TRACTOR MODEL	APPROX. MAX. TRACTOR BHP	IMPLEMENT MAKE AND MODEL	COUPLING IN PTO DRIVE	MAX. STARTING TORQUE		MAX. OPERATIONAL TORQUE PEAKS		AVE. TORQUE UNDER NORMAL OPERATING CONDITIONS, LB-IN	WORK BEING PERFORMED
					WITH NORMAL CLUTCH ENGAGEMENT, LB-IN	WITH RAPID CLUTCH ENGAGEMENT, LB-IN	AVERAGE CONDITIONS, LB-IN	NEAR PLUGGED CONDITIONS, LB-IN		
1	1	35	ENSILAGE HARVESTER A	STANDARD	4,900-6,400	10,800-15,370	4,680-6,390	5,450-7,140	2,720	CHOPPING HEAVY DRILLED CORN
2	1	35	ENSILAGE HARVESTER A	SPEC. SLIP		8,660*	5,112-5,723	6,025-6,865	3,200	CHOPPING HEAVY DRILLED CORN
3	9	40	ENSILAGE HARVESTER A	STANDARD		11,600	4,700-4,925	6,200-6,025	3,261	CHOPPING HEAVY DRILLED CORN
4	1	35	ENSILAGE HARVESTER B	STANDARD	2,600-4,000*		3,520-3,820	3,960-7,630*	2,390	CHOPPING HEAVY DRILLED CORN
5	1	35	FORAGE HARVESTER C	STANDARD		14,600	3,730-7,200	6,370-7,200	2,870	CHOPPING GREEN ALFALFA
6	1	35	FORAGE HARVESTER C	SPEC. SLIP		9,800-7,530*	5,230-8,700	6,100-8,700	3,270	CHOPPING GREEN ALFALFA
7	1	35	FORAGE HARVESTER C	STANDARD		12,500-10,900	6,060-7,460	9,500	3,600	CHOPPING GREEN ALFALFA
8	1	35	FORAGE HARVESTER C	STANDARD		21,400				ATTEMPTING TO START A PLUGGED MACHINE
9	1	35	CORN PICKER D	STANDARD	1,570-1,740	3,990	622-1,031		727	PICKING CORN
10	1	35	BALER E	STANDARD		18,300-20,600	5,860-7,470	12,100	1,140	BALING ALFALFA
11	1	35	BALER E	STANDARD	13,100		6,550-8,140	11,600-15,000	1,545	RECHECK OF TEST 10
12	1	35	BALER E	SPEC. SLIP	10,700-12,100*	10,700-12,100*	7,250-8,920	11,500-13,300*	2,250	BALING ALFALFA
13	1	35	BALER E	SPEC. SLIP	10,100*		8,600-11,100	10,350-12,600	1,580	BALING STRAW
14	9	40	BALER E	STANDARD	12,250		7,749-10,945	10,960-12,095	1,938	BALING ALFALFA
15	1	35	BALER E	STANDARD AND UNIVERSAL JOINTS ALIGNED			4,601-5,867		1,383	BALING ALFALFA
16	1	35	BALER F	STANDARD	16,500		8,600	22,700		BALING ALFALFA
17	1	35	BALER F	SPEC. SLIP	5,000*	5,000*	5,000*	5,000*		BALING ALFALFA
18	1	35	COMBINE G	STANDARD		10,100-16,600*	3,760	9,380	1,890	COMBINING WINDROWS
19	1	35	COMBINE G	SPEC. SLIP			7,150	7,760-9,130	1,700	COMBINING WINDROWS
20	1	35	COMBINE G	SPEC. SLIP		7,350-8,650*	4,160-4,200	7,470	1,600	STRAIGHT COMBINING
21	2	25	HAMMER MILL H	STANDARD	9,030	17,500-20,150	4,145	7,270	2,700	GRINDING EAR CORN
22	1	35	HAMMER MILL H	STANDARD	6,130		3,740*	14,900	2,140	GRINDING EAR CORN
23	1	35	HAMMER MILL H	SPEC. SLIP	8,230*	8,230*		6,920	4,210	GRINDING EAR CORN
24	4	45	HAMMER MILL J	STANDARD	18,150	25,800	7,800	13,000	5,450	GRINDING EAR CORN

* SAFETY CLUTCH IN PTO LINE SLIPPED LIMITING TORSIONAL LOAD TO THIS VALUE

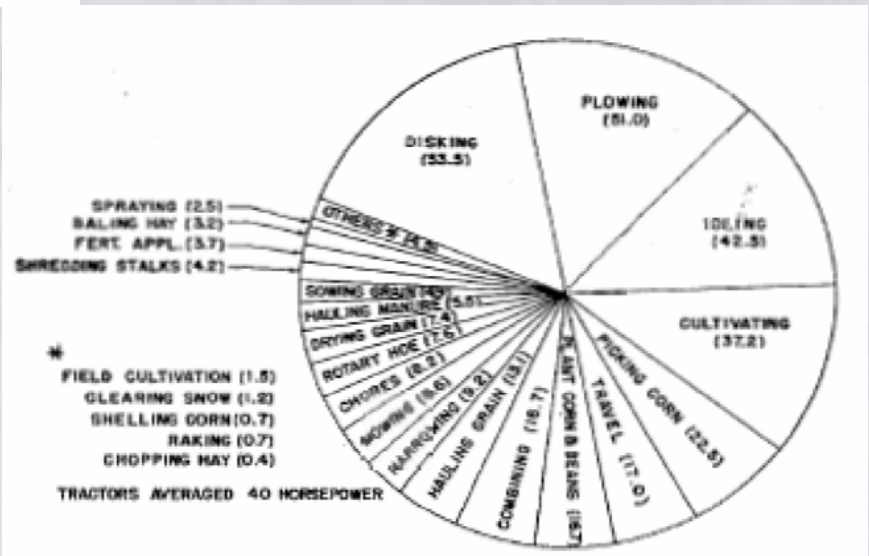
Technical Accomplishments: Task 1: System Study



Engine horsepower and speed for corn picking, subsoiling, field cultivating and soil packing

Distribution of hours of tractor use by operations

(average of 340 hours for 25 tractors)



Technical Accomplishments: Task 1: System Study

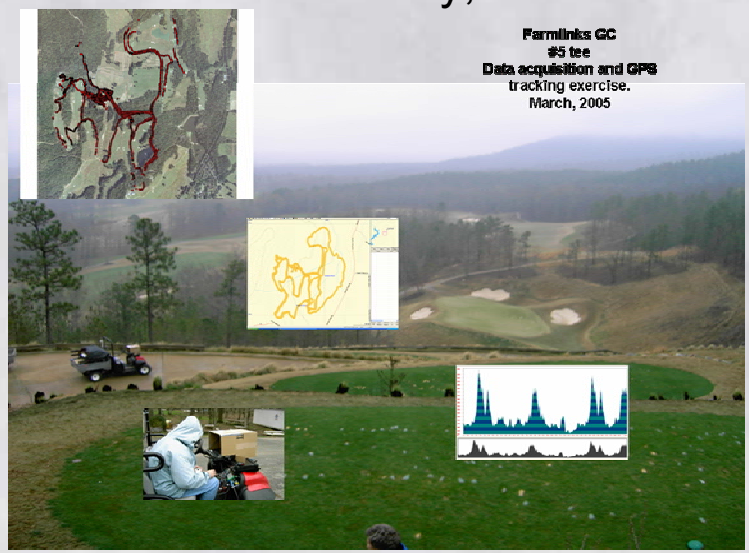
- 20 kW (26 hp) example:
  - In order to meet or exceed the performance of a traditional IC engine the hybrid fuel cell system would need to:
    - Have similar of greater torque reserve
    - Meet or exceed the rated power at operating speed
    - Be of equivalent or smaller size, weight, and weight distribution

- With the same tractor frame, a system with two electric motors, one for the drive and one for the PTO would be utilized. This would need to be a battery / fuel cell hybrid system, with the battery pack capable of meeting power spikes

Technical Accomplishments: Task 2: Impulse and Vibration Study

A Toro Workman 3000 tractor has been fitted with an electric power train, accelerometers, and is awaiting installation of the electric motor

A fuel cell hybrid Workman e2050 was operated at Farmlinks Golf Course (Alabama), and generated data for operating speeds, motor current, and hybrid voltage stability. The Workman was also tied to a GPS system, to allow for synchronization of collected data, the vehicle activity, and location.



Technical Accomplishments: Task 3: Air Quality Study

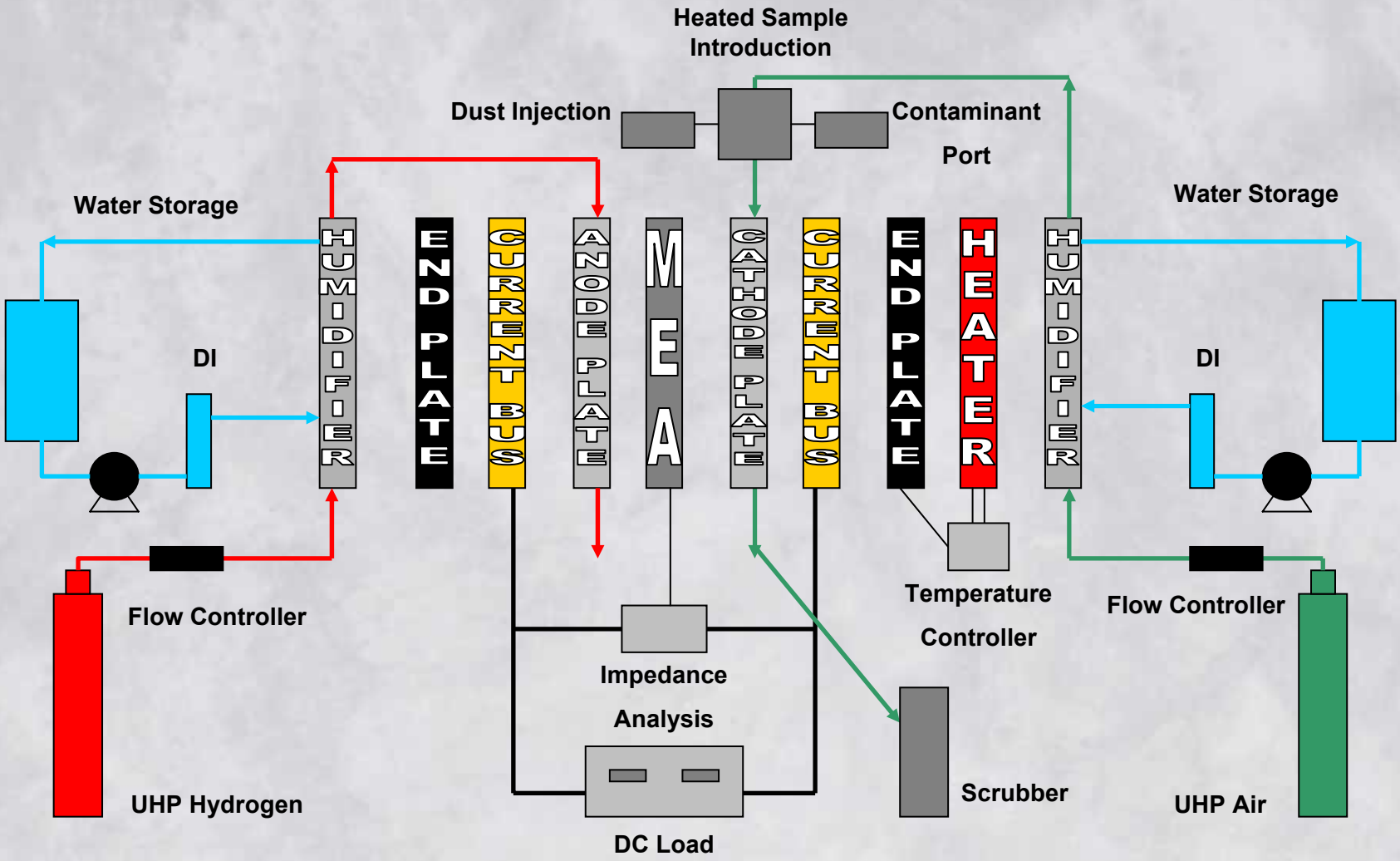
- Air contaminant database under construction; this database will identify contaminants for investigation in the eight, single cell, test systems.

  - Sourced from:
    - Literature search internal and external to Donaldson
    - On-site air sampling of select off-road environments (i.e. mining, construction, airport, agriculture, grounds care)

- Fuel cell air quality test systems designed, and components ordered. The test systems are currently under construction.

Technical Accomplishments: Task 3: Air Quality Study

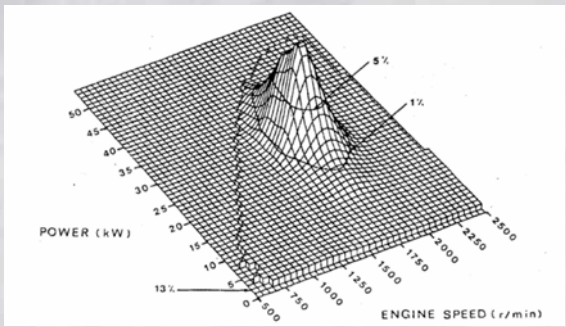
Test System Schematic

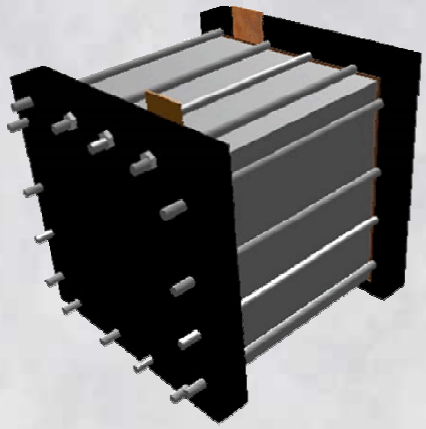


Future Work - 2005

- During the rest of this year the following tasks will be accomplished:

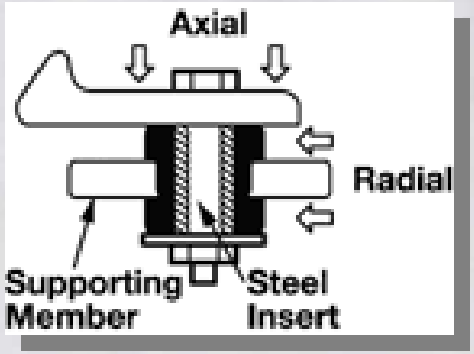
Identify fuel cell operating requirements	05/27/05
Identify mechanical stresses to the fuel cell	06/24/05
Provide power train recommendations	06/24/05
Prepare source identification graph (vibration & impulse)	07/22/05
Impulse & vibration testing	10/21/05
Provide impact and vibration testing results	11/11/05
Test fuel cell system, post vibration testing	12/09/05



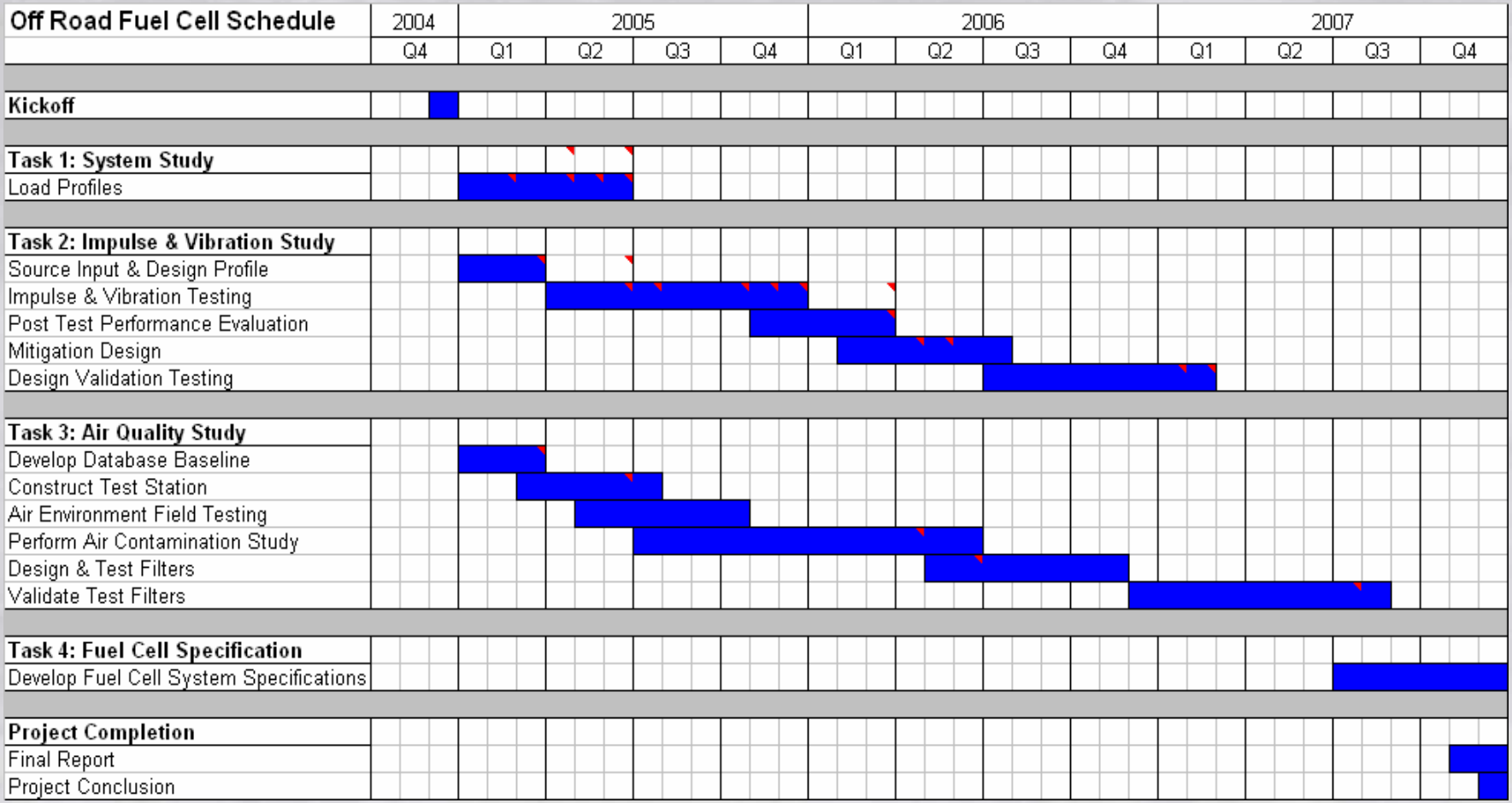


Future Work - 2006

- Next Year the following tasks will be accomplished:
  - Identify system vibration dampening strategies 03/01/06
  - Delivery of air purifying and noise dampening solution 04/01/06
  - A Toro Workman will be provided for testing 04/29/06
  - List recommended air purification practices 06/01/06
  - Build an implement dampening system 09/01/06



Schedule


Off Road Fuel Cell Schedule
2004
2005
2006
2007
Q4
Q1
Q2
Q3
Q4
Q1
Q2
Q3
Q4
Q1
Q2
Q3
Q4
Kickoff
Task 1: System Study
Load Profiles
Task 2: Impulse & Vibration Study
Source Input & Design Profile
Impulse & Vibration Testing
Post Test Performance Evaluation
Mitigation Design
Design Validation Testing
Task 3: Air Quality Study
Develop Database Baseline
Construct Test Station
Air Environment Field Testing
Perform Air Contamination Study
Design & Test Filters
Validate Test Filters
Task 4: Fuel Cell Specification
Develop Fuel Cell System Specifications
Project Completion
Final Report
Project Conclusion

Hydrogen Safety

The most significant hydrogen hazard associated with this project is:

The operation of the single cell air quality test systems at the IdaTech facility. These systems are the only portion of this program which will actively utilize hydrogen.

Hydrogen Safety

Our approach to deal with this hazard is:

To utilize IdaTech's experience in hydrogen production, and handling to provide a safe operating environment. IdaTech is an ISO 9001 company, which has acquired UL and CE certification on equipment in the field, and has hundreds of man years of experience in hydrogen production and utilization.

IdaTech's test facility is equipped with hydrogen detectors which are connected to hydrogen sources to shut off in case of hydrogen detection.

IdaTech is familiar with UL and CE standards as pertaining to stationary and portable fuel cell and reformer applications, and will continue to put into practice these standards. These include standards from ANSI/CSA FC-1, ANSI/CSA FC-3, CSA 1.01 FC Supplemental, UL 2075, CGA G5.3, NFPA 70 article 692 , NFPA 853, and other applicable standards.