This is the quarterly status report for the 21st Century Locomotive Technology project, DOE Award DE-FC04-2002AL68284. This report covers activities performed April 2005 to June 2005.

**TASK 1: ADVANCED FUEL INJECTION**

**OBJECTIVE**

**PROGRESS SINCE LAST REPORT**

**PLANNED ACTIVITY FOR NEXT QUARTER**

**TASK 3: HYBRID ENERGY STORAGE**

**SUBTASK 3.3: LAB TEST ADVANCED ENERGY STORAGE PROTOTYPE MODULES AND SYSTEM**

**SUBTASK 3.6: INTEGRATE SYSTEM AND TRACK TEST HYBRID LOCOMOTIVE WITH ADVANCED EMS CONTROLS**

**TASK 4-TRIP OPTIMIZER**

**SUBTASK 4.3: FABRICATE FUEL OPTIMIZER HARDWARE AND SOFTWARE**
Task 1: Advanced Fuel Injection

Objective

Develop and demonstrate an advanced fuel injection system to minimize fuel consumption, while meeting Tier 2 emissions levels.

Progress since last report

Over the last quarter, experimental work has continued on the advanced fuel injection task. The experimental efforts have been focused on performance mapping of the High Pressure Common Rail (HPCR) system on a locomotive single cylinder engine at notch 4, or part load operation. The variables explored include rail pressure, main injection timing, and pre and post injection quantities and timings.

Experimental milestones accomplished over this quarter:

- Explored NOx versus SFC tradeoff as a function of fuel rail pressure and start of combustion. The engine performance is unexpectedly insensitive to fuel pressure on the single cylinder locomotive engine at notch 4.

- Completed screening experiments with one to four injection events per stroke. Small pilot injections and small post injections had little leverage on the NOx versus SFC tradeoff curve.

- When multiple injections are delivered, each with substantial fraction of fuel, there is potential to improve or worsen the NOx versus SFC tradeoff by a measurable amount. Split injection schedules also have modest leverage on particulate matter.

Hardware improvements in progress:

We are in the process of upgrading the Bosch common rail fuel injection hardware. The fuel pump will continue to be driven with an external electric motor. The injector will be changed to reflect a current Bosch design. This injector has an additional safety feature and is expected to decrease the variation in the shot-to-shot injected volume. The new injector is currently being evaluated on an off-engine injection measurement device.

Planned activity for next quarter

The new injector design will be tested at notch 8 and notch 4 to assess if a performance differences can be measured between the injector designs. Finally, the HPCR optimization will continue to include other speed and load conditions.
Task 3: Hybrid Energy Storage

Subtask 3.3: Lab test advanced energy storage prototype modules and system

Long-term cycle testing of eight sets of cells continues. Testing for this project is expected to be completed next quarter.

An electrical test program was begun to study behavior of battery cells below operating temperature, in particular to assess any potential damage. The test plan required a range of test voltages to be applied to battery cells for defined periods, in increasing duration, as shown schematically in Fig. 1. The cells will be inspected and tested at operating temperature after each voltage application to determine their status.

![Diagram of test matrix](image)

**Fig. 1:** Cold cell energization test matrix: 4 voltage values and 6 durations.

A shock and vibration test plan was defined to identify failure modes of the existing commercial off-the-shelf battery design. A battery was torn down to understand the internal construction and pristine, pre-test conditions. The test sequence consisted of random vibration with a defined spectral density to reflect the locomotive environment, accelerated to compress a 20-year life into several tens of test hours, in addition to a sequence of representative shocks. A test performed on a room-temperature battery showed significant internal insulation wear, with more than one possible mode of insulation failure. A second test at operating temperature also exhibited insulation failure early in the test sequence. To clarify the failure modes, it was decided jointly with the vendor to manufacture a test battery with partly modified internal configuration and internal instrumentation, for a follow-up vibration test to definitively identify the failure modes. This battery is expected to be ready for testing in the July-September 2005 quarter.
Subtask 3.6: Integrate system and track test hybrid locomotive with advanced EMS controls

The on-locomotive track test results acquired in November and December 2004 and January 2005 were analyzed. The November and January data successfully predicted the battery SOC and validated the Energy Management System enhancements developed in Task 3.4. Resulting statistics showed that the battery SOC was estimated within 8% of true value with 95% confidence. The method was shown to be robust enough to operate on a locomotive with noisy sensor data.

Task 4-Trip Optimizer

Subtask 4.3: Fabricate fuel optimizer hardware and software

We completed a simulation lab with two full-scale operational control interfaces to the underlying software - both a standard GE desk console control employed in Dash 9’s and AC-44000’s as well as a low cost AAR standard control console that is widely found on many locomotives in the North American fleet. These two platforms now form the basis of our simulation demonstration. A separate PC-class computer with multiple displays to show the computed system state complements the main control console. This provides a simple low cost environment in which to evaluate the additional display requirements for Trip Optimizer, and ultimately to enable experienced engineers to work with an approximation to the environment they would experience on the rail.