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Task 2 Deliverable Report

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Emission Reductions and Compliance with Texas State Implementation Plan for CTI's Retrofit Technology

Task #2

FINAL REPORT

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1. Background

This report outlines the potential contributions of CTI's technology towards the goals of the Texas State Implementation Plan. It is based on two factors: technology capabilities in terms of emission reductions for typical on-the-road diesel vehicles, and eligible truck inventories in certain areas in Texas, as defined by TCEQ. Discussions will focus on NOx and VOC reductions, marketing, and inventory data for eligible trucks within certain truck fleets.

In as much as the above criteria is simple, the implementation of most, if not all retrofit technologies, is hampered by a multitude of other factors that can either speed up or slow down retrofit plans. Typical factors include: age of the vehicle, annual driven mileage, market/owner cooperation, reliability and durability in real-life versus lab declared emission reductions, amount and percentage of emission reductions, limitations by external factors on retrofit (such as 2002 and newer model years), liability issues associated with new hardware, and most importantly cost effectiveness (mainly in dollars per ton of pollution reduced). This report addresses these issues by looking at the costs and benefits based on the best known facts. An analysis of the competition in the marketplace is also provided. Further, recommendations regarding the potential and limits associated with the use of exhaust gas recirculation (EGR) on diesel vehicles are presented.

2. Summary & Overview of CTI's Technology & Capabilities

CTI's technology is based on a well-known automotive NOx reduction strategy, the use of Exhaust Gas Recirculation (EGR). It is well documented that EGR can reduce NOx up to 90% in certain operating modes. However, the penalties associated with EGR are fuel penalty and increased particulates, HC and CO emissions.

The strategy employed by CTI is based on capping the fuel penalty at or below 5%. The strategy for dealing with increased PM, HC, CO is based on the use of CTI's proprietary particulate converter for PM reduction as well as a diesel oxidation catalyst for HC and CO reduction. Based on performance data, it is anticipated that the particulate converter and the oxidation catalyst will not only control the increase in these pollutants, but will also reduce these pollutants below the base-line values. Due to a substantial increase in PM emission due to aggressive EGR injection, the need to increase the particulate converter efficiency became evident from initial mapping test data. To maintain PM reduction as high as possible, the particulate converter is refined and enhanced to achieve net PM reduction despite increase in baseline PM emission. PM reduction is estimated to stand at net 50% to 85%.

Initial in-house EGR mapping test data on a Caterpillar 3406 engine demonstrated the capability of an aggressive EGR injection strategy to lower NOx emission and still keep the fuel penalty below 5%.

For old engines having NOx emission of 10.7 gms/bhp.hr, the EGR/particulate converter/oxidation catalyst can bring NOx down to the 3 to 3.5 gms/bhp.hr range, which is a substantial reduction. For engines having NOx emission of 4 to 5 gms/bhp.hr, the control strategy can bring NOx down to 1.48 to 1.85 gms/bhp.hr, which is lower than 2002 emission standards. These reduction percentages will be finalized upon conducting formal EPA verification tests at Southwest Research Institute. CTI elected to defer implementation of EGR on engines having baseline NOx emission of 10.7 gm/bhp.hr for the next round of verification since all of these engines are mechanical and obtaining an electronic signal representing engine load/torque requires additional developmental work beyond the scope of this project.

CTI's technology also reduces VOCs. However, such reductions are small when compared to NOx reductions, and are not addressed in this report. It should be noted that VOCs, in conjunction with NOx, are major contributors to the formation of smog.

Originally, CTI elected to develop an EGR-based retrofit package for both the CAT 3406 and the International 7.3L diesel engines. Further market analysis focused on engines

used with public municipalities since almost all of them are eager to lower pollution from their fleets. This led to the selection of CAT engine 3126 instead of CAT 3406, since it is popular in metropolitan areas. Due to cost overruns, the International 7.3L engine kit is postponed.

Upon successful implementation of retrofit kits for the above engine family, CTI plans to extend the verification to additional popular 2 to 4 engine groups in 2008.

Demo units are planned for installation in the second half of 2007 in Houston and Dallas, Texas. Upon verification, CTI will be in a position to provide the product for retrofit application starting at the beginning of 2008. The demo units are intended to seed the market, to acquaint TCEQ and end users with the product, and to ensure customer satisfaction leading to large retrofits.

Based on a previous market assessment report by Good Company Associates, the populations of trucks within TERP counties having CAT 3126 stands at 9,172, out of a total of 288,346 registered engines, which represents 3.2% of the total engine population. By extending the verification next year to: 1) Cummins N14 (population of 22,068), 2) Detroit Diesel Series 60 (population of 24,846) and 3) International DT 466/DTA 466 (population of 17,074), a total of 63,988 vehicles can be added to the eligible retrofit engines. In this case, the total eligible engines could increase to 73,160 or 25% of the total eligible engines within TERP counties. Considering the fact that no single technology is a cure for all emission needs through retrofit, such broader availability of CTI's technology will be a very adequate and viable tool towards the goals of the Texas State Implementation Plan.

An observation is made with regard to old diesel trucks built before 1990. These trucks emit large amounts of NOx (10.7 gms/bhp.hr) compared to trucks built after 1991, which emit 4 to 5 gms/bhp.hr. The cost of retrofit old or new vehicle is essentially the same. Further, NOx emission reduction on old trucks is in the 65 to 70% range, or the equivalent of 6.0 to 7.0 gms/bhp.hr. On the other hand, the NOx reduction for engines built after 1991 is estimated at 60-65%, or the equivalent of about 3.0 gms/bhp.hr. The ratio of NOx reduction (benefit) between old trucks and newer ones is significant. This is a compelling case to retrofit old trucks. The case of old trucks is hampered by the fact that such trucks have little remaining useful life span, low annual mileage, and the cost of retrofit could be very close to the market value of such an old truck. In an attempt to recommend a reasonable strategy, old trucks having five years remaining life span and having annual mileage in excess of 30,000 miles should be recommended for retrofit. Even if the life span for such trucks is close to five years, the retrofit kit can be treated as property of the

State of Texas. After an old truck retirement, the state can exercise its right to remove such a retrofit kit and install it on another vehicle. The cost of removal and replacement is currently estimated at $3,000. When considering the fact that the life span of a retrofit kit could reach 7-10 years, such removal and replacement costs could be justified in some cases.

3. Current Targeted Retrofit Projects

The current targeted retrofit projects are for the CAT 3126 diesel engines. As much as the Texas SIP is clear regarding objectives and goals with broad and vast alternatives, the emission reduction scenarios and related benefits is a complex situation. For example, the State of Texas is in attainment status for PM pollutants. However, PM is a serious localized pollution issue that has received considerable attention and funding allocations from the EPA and other agencies. TCEQ acknowledges the benefit and the need of PM reduction, but may not have budget allocations, per se for PM retrofit. A typical case here is school buses. These vehicles have low NOx emissions due to low annual mileage. However the health effects on children because of exposure to PM and crankcase ventilations have received considerable attention from the EPA and other groups that provide funding nationwide. It would be advantageous to capitalize on federal grants, such as from EPA and CMAQ, as well as others and augment them with TCEQ allocations to achieve the combined PM & NOx reductions. This is a most effective strategy for leveraging retrofit projects using federal funds for the ultimate benefit of Texas citizens. In as much as CTI's retrofit strategy capitalizes on total pollution reductions such as PM, NOx, HC, CO, toxicity and nano-particles, this is simply a unique one-stop visit in the retrofit market. Further, certain localities in Texas could be classified as non-attainment when PM 2.5 particulate standards will take place in the near future.

The following scenarios illustrate the case of retrofitting trucks that have the subject engine family and the associated emission reductions.

3.1 The Case of CAT 3126 Truck Engine

This case is based on eligible trucks in TERP counties.

Assumptions:

1. Retrofit costs: $12,000 for quantities over 100 retrofit kit
2. Annual Mileage: 30,000 miles/year for 1998 through 2001 model year engines
3. Penetration: 50% of eligible TERP counties engines, or a total of
   0.50 x 9,172 =4,586 vehicles
4. NOx Reduction: 60% for 1998 to 2002

Emission Reduction Scenarios for CAT 3406

Item	Model Year 1998-2002 (4,586 engines)
NOx Reduction tons/year/vehicle	**0.42**
NOx Reduction for targeted penetration ▪ **Tons/Year** ▪ **Tons/Day**	 **963** **2.65**
Retrofit (acquisition) Costs	**$55 million**

4. Upcoming Retrofit Project

Based on the Texas Market Assessment Report by Good Company Associates and CTI, three additional diesel engines have a large population in the State of Texas. These are:

1. Cummins N14 diesel engine (population of 22,068)
2. Detroit Diesel series 60 diesel engine (population of 24,846)
3. International DT 466/DTA 466 (population of 17,074)

CTI intends to amend the verification of the particulate converter/EGR system in 2008. This will provide a broader scope for retrofit and assist with targeting high mileage trucks from the foregoing engine groups. No action is being taken until the verification of the CAT 3126 engine is completed.

5. Proposed Retrofit Ramping

The following scenario outlines a ramping strategy that takes into account the practical considerations relating to retrofit works. These are summarized as follows:

5.1 Verification by CARB & EPA

Verification for PM & NOx is anticipated to be in hand by December 2007/January 2008.

5.2 Acceptance of the Retrofit Technology by TCEQ & Host Companies

CTI plans to have demo units available in the Houston/Dallas areas starting by the end of 2007/early 2008. It takes 4-6 months of direct experience with the product to formulate an opinion and gain first-hand acceptance. It is imperative to have a high degree of reliability and durability in operation, and to determine that maintenance and service

procedures are within the know-how and level of experience of maintenance personnel. This may necessitate the presence of cognizant engineers in large TERP areas such as Houston and Dallas to support installation and maintenance issues as they may arise. These issues are not only limited to the retrofit product, but also the methodology and quality of installation.

In summary, we estimate it would be close to a year of hands-on experience to gain broad acceptance from host companies and maintenance personnel. Most of the host companies have been skeptical of various claims relating to retrofit technologies due to a multitude of inaccurate claims or broken promises by competitors. Although verification provides a good level of comfort, it is not a given for acceptance by host companies.

5.3 Manufacturing Ramp-up

CTI and its commercial arm, Truck Emission Control Technologies (TECT), will ramp-up manufacturing after verification, although manufacturing plans and alliances with major suppliers are essentially in place. Ramping will take place in three stages as described in Truck Emission Control Technologies Business Plan.

Based on the manufacturing ramp-up, TECT will be able to furnish 100 to 200 kits in the first 6 months of 2008. This can be followed by 500 kits for the remaining six months of 2008. Starting in 2009, CTI will be able to ramp up to 5,000 kits or more per year, if needed.

5.4 Establishment of Retrofit Centers

Another critical issue relates to what we refer to as “retrofit centers”. Such centers will be located in major retrofit areas, and we anticipate having 6 to 10 centers throughout the state of Texas. These centers will be staffed by highly qualified and trained technicians under the supervision of qualified engineers to deal with retrofit challenges, problems, and maintenance issues. There is no easy substitute for such centers. The primary responsibility is marketing and installation, which must adhere to strict installation procedures and quality controls. We plan on forming such centers through joint-venturing with large truck dealerships, truck muffler shops, or stand-alone retrofit centers. We target the formation of 4-5 centers in 2008. Any additional centers will follow later.

5.5 Funding Allocations & Retrofit Ramp-Up

Funding allocation and coordination of state and federal funds for retrofit projects in Texas will be subject to funds available. This is outside of the scope of this document.

The projected retrofit scenario taking into account factors relating to ramp up is:

Calendar Year	200	2008	2009	2010	2011
Retrofit Units	5	600	5,000 or more	5,000 or more	5,000 or more

6. Cost Effectiveness of CTI's Retrofit Strategy

This analysis is for the CAT 3126. The following is a summary of cost effectiveness.

6.1 Cost Analysis for the CAT 3126 Diesel Engine

This analysis is based on the bulk of CAT engines for model years to be retrofitted. There is a trade off between model year and emission reduction in tons per year.

Assumptions:

- Acquisition costs per retrofit kit: $12,000
- Life span of retrofit kit: 7 years
- Annual operating costs (fuel penalty & maintenance): $400
- Average NOx reduction per vehicle per year: 0.42 tons for trucks (1990-2001 model year)

Analysis:

- Annual costs = 12,000/7 + 400 = $2,114
- Average NOx reduction costs = 2,114/0.42 = $5,034 per ton

7. Comments on Cost Effectiveness of CTI's Retrofit Strategy

1. These costs are based on amortizing the total hardware costs for the reduction of NOx only. In reality, there are also additional reductions in VOCs, HC, CO, particulates, toxicity, and nano-particle counts. If a value is assigned to all other pollutant reductions, the NOx reduction costs could be half the stated values.
2. Other reductions in pollutants such as PM can leverage federal grants which could lower the value of NOx reduction costs per ton to the state of Texas.
3. The NOx reduction costs are dependent on the accumulated annual mileage. Truck annual mileage varies from an average of 20,000 to as high as 100,000 miles per year. The stated cost effectiveness is an average value based on conservative low annual mileage of 30,000 miles/year. For high mileage vehicles, the NOx reduction costs in $/ton would be reduced. Therefore, the implementation of retrofit strategy should take into account high mileage fleets first.

4. It should be noted interstate/highway trucks are the true culprit of high NOx emissions. Such trucks accumulate 150,000 to over 200,000 miles per year and can generate up to 6 tons of NOx per truck per year for 5.0 gms/bhp.hr NOx emission. In such a case, NOx reduction could be as high as 3 tons per year per truck. Unfortunately, reductions from such trucks are not concentrated in TERP eligible areas and could go outside of the State of Texas. The case of such trucks requires further studies to quantify the effectiveness of retrofitting such vehicles in Texas.

8. <u>Competitive Assessment</u>

The following chart is a summary of alternative retrofit technologies and their effectiveness, costs, limitations, etc. This chart is based on marketing data collected in 2005/2006. Costs are based on the best available data and could be subject to change. Most costs are dependent on volume.

Dominant NOx Retrofit Technologies
Retrofit Costs, Status, Effectiveness

Supplier/ Technology Provider	Verification Status	Installed Costs	Total NOx Removed Tons/truck/year	Costs Effectiveness $ /TON	NOx Reduction	Market (actual installation)
Ammonia-Urea Extengine-ADEC	CARB Verified	$24,979	3.95	$6,327	80%	Off-Road C5.9,150-200hp
Cleaire-Lonestar (NOx only solution)	Ongoing	$12,000 (estimate)	1.48	$8,105	30%	On-Road, '93-03
STT Emtec-EGR	Ongoing	$20,307	2.47	$8,230	50%	Few are on-the-road
Re-engine (assumes Drop-in of '04 Compliant engine	Com'l/ EPA	$25,000	2.47	$10,131	50%	On/off road, marine
Cleaire-Longview	Com'l CARB	$15,000	1.23	$12,158	25%	On-road, '93-03

Notes:

1) SCR – SNCR operating costs are high, primarily due to ammonia/urea, and maintenance costs.
2) STT Emtec-EGR costs include particulate traps and EGR technology and are similar to CTI's system. The product is hampered with lack of effectiveness of a trap system capable of supporting increased in PM emission, and it has a number of reported failure rate in field.
3) Total NOx removed is based on high mileage of 150,000 miles per year for heavy heavy-duty trucks.