**Draft Proposal**

**Collection of Activity Data from On-Road**

**Heavy-Duty Diesel Vehicles**

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Check if applicable:

Animal subjects \_\_\_\_\_\_\_

Human subjects \_\_X\_\_\_\_

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# Abstract

The implementation of stringent NOx standards for 2010 heavy-duty engines is an important step for the State of California to meet upcoming ambient air quality standards for ozone and PM. These standards are primarily being met with selective catalytic reduction (SCR) aftertreatment systems. SCR reduces NOx in the exhaust stream, but requires adequate temperatures (typically at least 200°C) for the reduction to take place. However, there will be times when this temperature requirement is not met, such as right after engine start and during low loads experienced when the engine is idling, or when the vehicle is moving slowly on flat terrain. The frequency of low temperature and low duty operations varies for a truck depending on its type of vocation. In line-haul application a truck operates mostly with high load to maintain high-speed cruise, while the other trucks operate with frequent stops in local goods delivery application. As a truck activity changes, SCR functionality of the truck changes with implications for NOx reduction using SCR. Therefore, it is critical to characterize heavy-duty diesel truck activity profiles including duty cycles, number of engine starts, and engine soak time distributions, for trucks by vocation. The heavy-duty diesel truck activity profiles are fundamental for updating emission inventories, quantifying real-world NOx emissions from trucks meeting the new 2010 NOx certification standard, and determining if the certification standard should be revised.

The objective of this research is to characterize the heavy-duty truck activity profiles (e.g., duty cycles, starts and soak time) for different types of vocational uses (line haul, drayage, delivery, etc.) with the specific goal of identifying what fraction of the vehicle operation may be such that Selective Catalytic Reduction (SCR) functionality is challenged. The research will also put these results in context of the emission certification test cycle and provide an analysis of the representativeness of the certification cycle to real world emissions of nitrogen oxide (NOx) for the different types of heavy duty vehicles. The results will be used to improve heavy duty NOx emissions models, and to take a critical look at whether certification and compliance procedures need to be updated to account for the functionality of SCR.

# Introduction

For the State of California to meet upcoming ambient air quality standards for ozone and PM, considerable reductions in NOx emissions are needed. To achieve some of these reductions the NOx emission standard for heavy-duty on-road engines was reduced by 90 percent in 2010. Diesel engine manufacturers are in most cases using advanced engine exhaust aftertreatment, specifically SCR, to meet the new standard. SCR reduces NOx in the exhaust stream, but requires adequate temperatures for the reduction to take place. Typically, the SCR needs to be at least 200°C before significant NOx reduction is achieved. However, there will be times when this temperature requirement is not met, such as right after engine start and during low loads experienced when the engine is idling, or when the vehicle is moving slowly on flat terrain. The frequency of low temperature and low duty operations varies for a truck depending on its type of vocation. In line-haul application a truck operates mostly with high load to maintain high-speed cruise, while the other trucks operate with frequent stops in local goods delivery application. As a truck activity changes, SCR functionality of the truck changes with implications for NOx reduction using SCR. Therefore, it is critical to characterize heavy-duty diesel truck activity profiles including duty cycles, number of engine starts, and engine soak time distributions, for trucks by vocation. The heavy-duty diesel truck activity profiles are fundamental for updating emission inventories, quantifying real-world NOx emissions from trucks meeting the new 2010 NOx certification standard, and determining if the certification standard should be revised.

This draft research proposal is the College of Engineering – Center for Environmental Research and Technology (CE-CERT), University of California at Riverside (UCR) response to the solicitation on “Collection of Activity Data from On-Road Heavy-Duty Diesel Vehicles”.

# Previous Research

Understanding heavy-duty truck activity profiles is critical to the development of heavy-duty truck emission inventories. UCR has conducted a number of research projects in this area for the past several years. Selected examples of these research projects are described below.

*Generating Heavy-Duty Truck Activity Data Inputs for MOVES*

The use of wireless communication or telematics technology has been increasingly adopted by the fleet management industry. There are now a large number of fleet vehicles that are equipped with telematics-based vehicle tracking and monitoring systems which can wirelessly transmit the position information of the vehicles that is obtained from an on-board GPS device to a system server on a periodic basis. Furthermore, some systems are also connected to the vehicle’s on-board diagnostic bus (OBD-II for light-duty vehicles and SAE J1939 bus for heavy-duty trucks), allowing not only the vehicle’s position but also vehicle and engine operating conditions (e.g., engine speed, fuel use, etc.) to be monitored and reported in real-time. These vehicle tracking and monitoring systems have potential to be a very rich source of HDT activity data.

In this research, UCR acquired a large-scale truck telematics dataset from a collective fleet of more than 2,000 heavy-duty trucks (HDTs) across the U.S., and used it to develop several of the HDT activity data inputs required by the U.S. Environmental Protection Agency’s Motor Vehicle Emission Simulator (MOVES) model. The developed HDT activity data inputs include vehicle miles traveled by road type, by weekday/weekend, and by hour. They also include average speed distribution as well as trip starts locations and distributions (see Figure 1).

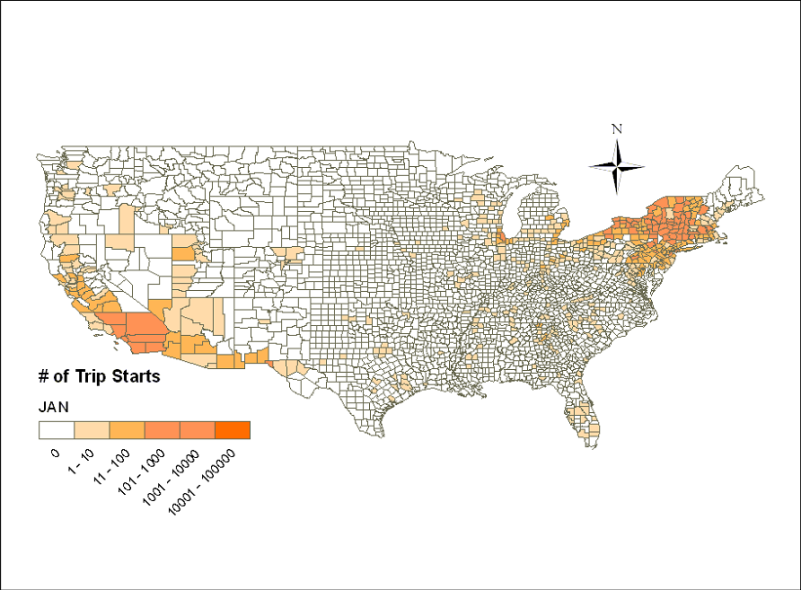
 

Figure 1. (Left) Number of trip starts in U.S. counties, (right) number of trip starts by time of day

Based on the experience working with the dataset, it was found that the truck telematics data have several advantages. First, they include GPS information of the HDTs, which can be used to derive various forms of HDT activity data such as miles traveled, speed, trip starts, and idle time in detail. Second, they are continuously collected, thus allowing temporal distributions of HDT activity to be developed by hour, day, and even month. Third, they can be collected from a large number of HDT samples at a time, improving the confidence in the derived HDT activity data. As an example, the dataset used in this study includes data from more than 2,000 HDTs while one of the largest instrumented vehicle studies of HDTs ever conducted in the U.S. had only 120 HDTs. Lastly, by coupling them with proper vehicle and fleet characterization, the truck telematics data can be used to develop vehicle activity data for specific truck categories and vocation types.

On the other hand, it is important to understand the limitations of the truck telematics data as well. First, they are collected at a much coarser interval (e.g., 30-second to 5-minute depending on the fleet) as compared to the data from instrumented vehicle studies, which are usually collected at a one-second interval. This may slightly affect the accuracy of the derived HDT activity data. Also, the data cannot be used for duty-cycle development. Second, they are collected from a subset of HDTs in the total population. Thus, they cannot be used to derive the absolute statistics of the HDT population such as total VMT.

*Review of Heavy-Duty Truck Cold-start Activity for Vehicle Emission Modeling*

UCR is working to support CARB in the update of its EMFAC model. One of the research tasks involves the review and estimation of HDT cold-start activity from existing literature and datasets. The number of trips or the number of starts per day is necessary for including start emissions in EMFAC. In addition to engine start frequency, the engine off time before a trip event (known as soak-time) is of interest since it relates to vehicle component temperatures and has a significant impact on start emissions. Cold-starts are of particular importance due to the higher emissions rates associated with them. They contribute significantly to emission inventories since cold engines produce much greater emissions than hot engines in the first few minutes following a cold-start.

In this research task, UCR: 1) conducted literature review on the availability of data for HDV cold-start events by truck service type for selected truck service types and for the state of California, 2) analyzed selected datasets to determine cold-start activity rates for three of the truck service types of interest (see Figure 2), and 3) provide recommendations for the number of cold-starts by truck service type and for future study to improve the quality of cold-start activity assumptions for HDTs.



Figure 2. (Left) Number of cold starts for short haul trucks, (right) number of cold starts for long haul trucks

# Project Objectives

The objective of this research is to characterize the heavy-duty truck activity profiles (e.g., duty cycles, starts, and soak time) for different types of vocational uses (line haul, drayage, delivery, etc.) with the specific goal of identifying what fraction of the vehicle operation may be such that Selective Catalytic Reduction (SCR) functionality is challenged. The research should also put these results in context of the emission certification test cycle and provide an analysis of the representativeness of the certification cycle to real world emissions of nitrogen oxide (NOx) for the different types of heavy duty vehicles. The results will be used to improve heavy duty NOx emissions models, and to take a critical look at whether certification and compliance procedures need to be updated to account for the functionality of SCR.

# Project Approach

Collecting data on heavy-duty truck activity and SCR inlet temperatures will greatly help provide a better understanding of the relationship between vehicle operation and SCR performance on a fleet basis. This will allow modelers to quantify the impact of deNOx performance issues due to low SCR temperatures on the California NOx inventory. Unfortunately, SCR inlet temperatures are a function of soak time, soak conditions, duty cycle, ECU calibration, model year, vehicle weight, and possibly many other factors, which vary by truck engine, category, and vocational use. There are 68 different SCR-equipped engines sold in California, see Appendix B. Additionally, there are 27 different truck categories in EMFAC2011, see Appendix A, some of which have multiple vocation types. Thus, the approach to data collection in this research needs to be strategic where a combination of data collection methods will be used to collect data from targeted truck categories and vocation types.

This section describes UCR’s approach and discusses tradeoffs and recommendations for achieving useful information to help quantify the impact of low temperature SCR performance. The approach to our proposal is slightly different than outlined in the original solicitation. The main differences are regarding the travel diaries, recruiting, and data logging.

We clearly understand the objective of this research as set forth by the California Air Resources Board (CARB), and are strongly confident that we have the necessary skills and experience to accomplish it. In doing so, there are several aspects to the project that need to be considered as discussed in this section to provide the context to our statement of work in the technical plan.

## EMFAC screening

California motor vehicle emission inventory model, EMFAC2011, categorizes medium (T6) and heavy (T7) heavy-duty diesel trucks by a combination of their geological operation boundaries and vocational uses (Appendix A). Further truck class categorization by the type of vocation is critical to understand truck activity profiles to estimate SCR functionality and to quantify emissions. For instance, current T6 instate heavy-duty trucks operate in multiple vocations including beverage distribution, mail delivery, local goods delivery and others. It is believed that activity profiles from a mail delivery truck, which may include multiple short trips (short soak time) with low exhaust temperature, will be different from a beverage distribution truck making longer soak duration while loading and unloading. Although the two trucks are in the same T6 instate truck category, the difference of their activity profiles may be statistically significant. The contractor will investigate types of vocations for each truck class in EMFAC2011, and conduct a screening analysis of identifying truck vocational use types by the magnitude of NOx emissions. Based on this screening analysis results, Tasks 2 and 3 will be conducted.

## Recruiting issues

It is not possible to include every truck categories in EMFAC2011 in this research. Instead, only selected truck categories that contribute the most to the state’s NOx emission inventories will be included. Then, major vocation types within the selected truck categories will be identified, and truck activity data from these vocation types collected and analyzed. Since we will sample trucks only from specific categories and vocations types, the recruitment will be quite challenging, especially for an emissions-related project under the current regulatory climate. Perhaps, the truck recruitment will be the most difficult part of this project. At the same time, it is the most critical part as we will not be able to proceed to collect and analyze data without a successful truck recruitment campaign.

Therefore, we are structuring our scope of work slightly different from what is stated in the solicitation. In our draft scope of work, truck recruitment will be a dedicated task that commands a certain amount of time and resources. This task will immediately follow the truck screening analysis and sampling design task. At the middle of the truck recruitment task and before the truck data collection task begins, a project status review will be conducted along with CARB to review the number of trucks successfully recruited. Then, a decision will be made whether and how to move forward with the remaining tasks. If the number of trucks recruited meets a target, then the project can proceed as planned. If the number of trucks recruited misses the target slightly, then additional project time and resources may be given or the targets may be adjusted. However, if it proves too difficult or impossible to recruit trucks that fit specific category and vocation type profiles to participate in this research, then CARB may terminate the project or request that a new proposal with a drastic change in research approach be submitted.

## Data collection considerations

Another consideration in this research concerns truck data collection methods and their tradeoffs. Three methods are being considered, including: 1) travel diary survey, 2) ECU data logging, and 3) GPS data logging. A summary of their pros and cons is provided in Table 1.

Table 1. Pros and cons of truck data collection methods being considered

|  |  |  |
| --- | --- | --- |
| **Method** | **Pros** | **Cons** |
| Travel diary survey | * Lowest cost per sample, thus allowing for larger sample size * Least invasive, which may make truck recruitment easier * Provide qualitative data (e.g., trip purpose) in addition to quantitative data | * Short data collection period (typically 1-2 weeks) * Semi-subjective and prone to human errors (e.g., underreported trips) * Only provide trip-related data; no detailed vehicle or engine operation data |
| ECU data logging | * Provide vehicle speed and engine operation data (e.g., engine RPM, fuel rate, etc.), including exhaust temperature, which is the key parameter of interest * High resolution data (e.g., 1 Hz) for long period (several months) | * Expensive data logger (~$1,400 per unit) * Most invasive as the data logger needs to be attached to the vehicle’s J1939 port |
| GPS data logging | * Provide vehicle location data in addition to vehicle speed, thus enabling spatial analyses (e.g., road type identification) * High resolution data (e.g., 1 Hz) for long period (several months) * Inexpensive data logger (~$200-$400 per unit) | * GPS “tracking” sometime leads to privacy concerns although the data will be scrubbed to protect vehicle identity. |

We understand that the choice of data collection method(s) will be also based on the costs. We are open to discussion with CARB to find an optimal solution that will satisfy both the objective and budget of this research. As a general idea, we provide rough cost estimates of some example options in Table 3. Detailed cost breakdown for each option is provided in the Budget section.

Instantaneous engine operation data can be acquired with engine control unit (ECU) or on-board diagnostic (OBD) data loggers. In addition to ECU/OBD data, if applicable, it is beneficial to also collect vehicle position data by global positioning system (GPS), which are time-synchronized with ECU/OBD data.

All quantitative trip information that can be derived from travel diary survey data, including the number of engine starts per day and soak time distribution per day, can also be derived from ECU or GPS data. We feel that the qualitative trip information that can be derived from travel diary survey data such as trip purpose is not critical for meeting the objective of this research. Also, travel diary surveys are typically conducted over a short period (1-2 weeks), while ECU and/or GPS data can be collected for several months. While the data collection costs for travel survey are lower than vehicle instrumentation, the derived trip information will be less accurate as they are subject to human errors.

We feel that the best data collection approach may be a combination of ECU and GPS-only data loggers. This approach reduces the hardware costs as compared to using ECU loggers for all truck samples while still providing both vehicle/engine operation and vehicle location data. The ECU data loggers can be strategically installed on a subset of truck samples in all the selected truck categories and vocation types. Or, they can be strategically installed on only a few targeted vocation types that are likely to have low-load duty cycles based on some perspective on fleet operations. In addition, there may be some possibility to move the ECU data loggers around depending on the fleet.

# Technical Plan

The following technical plan is broken down in to five tasks. Task 1 focuses on a strategic screening effort using EMFAC2011, Task 2 discusses the travel diary and recruiting efforts, Task 3 describes the recommended data collection method, Task 4 describes the data analysis approach, and Task 5 provides the details on the data reporting.

## Task 1. Screening analysis

We will conduct a screening analysis of the 27 truck categories in EMFAC and select a subset of categories that contributes the most to the state’s NOx emission inventories. The screening analysis will rely on EMFAC2011 and, to the extent that is applicable, MOVES2010b. In addition, recent literature on NOx emissions from different categories of trucks will be reviewed and, if relevant, used to augment the selection of truck categories to be included for the next tasks. After that, we will identify major vocation types within each truck category and design a sampling strategy for truck recruitment. The essence of Task 1 is to identify the magnitude of NOx emissions by types of vocational uses for heavy-duty diesel trucks.

## Task 2a. Truck diary survey

The solicitation recommended performing a truck travel diary surveys to be used to quantify the number of engine starts per day, soak time distribution, and other trip related details. Table 2 shows the list of information recommended as part of the truck travel diary survey.

Table 2. Information Included in Truck Travel Diary Survey



Based on the discussion above, UCR believes the value of the driver survey is less likely to provide the needed data to characterize the goals of this project. Thus, the truck diary survey is provided as an option as listed in the Budget section, see Table 6.

## Task 2b. Truck recruitment

We will set up one or two subawards specifically for truck recruitment depending on the total number of vehicles selected for this proposal. Each subaward is anticipated to be $25,000 for recruiting 100 trucks. This will require approximately 20 participating fleets assuming an average of five trucks per fleet. We have a good working relationship with the National Renewable Energy Laboratory (NREL) hybrid demonstration team. The NREL hybrid team has a large resource of green fleet contacts throughout California. The NREL fleet includes parcel, refuse, bucket, utility, and grocery Class 4, 7, and 8 diesel vehicles. In addition, UCR has good relationships with Tiax, Environ, and Digital Geographic who have completed several vehicle activity studies in California.

Furthermore, SCAQMD is also interested in the inventory of NOx emissions in light of the degraded performance of SCR systems and has agreed to help us find participating fleets. We also have good direct contacts with several local fleets that we can pursue. In addition, UCR realizes that CARB and many of the air districts may have fleet contacts that could be utilized to facilitate getting fleet participation over the range of vocation types needed. Thus, we believe that the fleet participation can be addressed in this scope of work.

Our approach to perusing recruitment will start with completing Task 1, then use that list of selected vehicle categories to query our sub award participants and partners. Those participants and partners who meet our requirements will be pursued for fleet contacts. Once the subcontractor is selected, we will work with them to solicit California fleets for our data logging requests. Those fleets that agree or who are interested will work with UCR for the final data logging installation.

GPS data is an issue with many fleets due to privacy. In the past UCR has shifted the GPS data to make vehicle tracking unavailable. This will be proposed to the fleets if necessary.

## Task 3. Data collection

In general the main goal for Task 3 is to collect activity data and develop truck activity profiles for each truck use type by vocation. The solicitation recommends utilizing ECU loggers to record various parameters with in the engine ECU data set. Table 3 shows a list of the vehicle and engine information, and ECU/OBD/GPS data recommended to be collected as part of this task. The cost of ECU loggers is significant and may prevent funding of this research effort where GPS loggers can still be of value and provide needed activity data. Thus, UCR proposes data logging with GPS-only systems to keep costs to a minimum and to increase the quantity of units to be tested. Thus, UCR will collect the data in Table 3 except the ECU data.

The scope of work is open to discussion if there is a need to adjust the effort of our data logging systems based on budgets and needs. It is assumed CARB may want to discuss the proposed scope of work and thus several data logging options are provided in the Budget section, see Table 6.

In the case of the optional travel diary survey, we would sub one or two contractors to perform the survey. The Transportation Sustainability Research Center (TSRC) at University of California at Berkeley (UCB), who has numerous experiences conducting this type of survey, has committed to be a sub to survey truck fleets in Northern California. In addition, they could assist with data logger installation and serve as an interface with those truck fleets. We are in discussion with another party who could play a similar role in Southern California.

Table 3. Vehicle and Engine Information, ECU/OBD/GPS Data



UCR will procure the data loggers, set up wireless data communication channels and data server, and perform the installation. The GPS loggers will be installed for approximately six months to ensure a wide range of activity data to quantify fleet behaviors. The GPS data will be logged at 1 Hz (i.e., second-by-second). We will also perform the uninstallation of the data loggers at the end of the data collection period.

In the case of the selecting the option for ECU loggers, UCR will procure the ECU loggers, set up wireless data communication channels and data server, and perform the installation. The ECU data will be logged at 1 Hz (i.e., second-by-second). We will also perform the uninstallation of the data loggers at the end of the data collection period.

## Task 4. Analysis

For each truck category and vocation type, we will analyze the ECU and/or GPS data to determine number of (cold) starts per day, soak time distribution per day, and other trip statistics (e.g., average distance, average duration, average speed, etc.). If travel diary survey is added, we will compare these trip statistics with those derived from the survey and make adjustments accordingly. Using second-by-second vehicle speed from the ECU and/or GPS data for each truck category and vocation type, we will also develop a representative chassis duty cycle and compare it with the certification cycle. If the GPS data is available, we will also GPS data-based chassis duty cycles by road facility type. The comparison between the developed duty cycles and the certification cycle will be performed in several ways, including, but not limited to:

* Create joint speed-acceleration frequency distributions of the developed duty cycle and the certification duty cycle, and then calculate the total absolute difference of the speed-acceleration cells.
* Create speed, acceleration, and vehicle-specific power distributions of the developed duty cycle and the certification duty cycle, and then conduct the Kolmogorov-Smirnov test to test a null hypothesis that the distributions of the developed duty cycle and the certification duty cycle are from the same population.

## Task 5. Final Report

A final report will be provided to CARB that will include a description of the screening results, recruiting approach, the data logging methods and difficulties, data analysis and results. The results will include vocation type comparison to certification duty cycles which will include statistics of speed, duration, acceleration, and ECU data if available.

CE-CERT will have a Kick-Off meeting with ARB staff prior to the commencement of the project and prior to commencing the dialoging portion of the project. In addition, at the conclusion of the project, CE-CERT will present the results to CARB staff.

# Project Schedule

The duration of this proposed project will be completed in 24 months from the start date. This includes 6 months for CARB review of the draft final report and delivery of a revised final report and data files to CARB. The project schedule is shown in Table 4. It is expected the recruitment effort will take 6 months and the data logging effort will last also for 9 months to allow collection of 6 months of data. UCR will target installing as soon as some fleets are available then start retrieving those systems first at the end of the data collection task. It is expected the data analysis portion will take two months and the final report will take four months to complete.

A project review is proposed at the middle of the truck recruitment task and before the truck data collection task begins, to assess the number of trucks successfully recruited. A decision will be made whether and how to move forward with the remaining tasks. If the number of trucks recruited meets a target, then the project can proceed as planned. If the number of trucks recruited misses the target slightly, then additional project time and resources may be given or the targets may be adjusted. However, if it proves too difficult or impossible to recruit trucks that fit specific category and vocation type profiles to participate in this research, then CARB may terminate the project or request that a new proposal with a drastic change in research approach be submitted.

Table 4. Project schedule (in months)



# Project Budget

The total cost for the proposed project is $299,527. This total budget includes the screening effort, recruiting 100 trucks from 20 fleets, installing 100 GPS – only data loggers, analyzing the data with a focus on the certification level for NOx emissions and providing a comprehensive summary report. In addition the total cost covers quarterly progress reports, status updates, and technical discussions with ARB.

The budget only includes GPS data loggers. The GPS loggers are capable of providing real time vehicle activity data that can be analyzed for and basic duty cycle information. Engine load can be estimated from accelerations, grade, and other details from this real time data. However, to understand engine load and true SCR performance, UCR recommends installing some ECU loggers on critical vocations. If 20 of the GPS units are replaced with ECU loggers this will provide additional engine related information such as exhaust temperatures, engine load, and other engine related information. The upgrade to 20 ECU loggers and 80 GPS loggers will increase the total project from $299k to $362k. To increase the scope of work from 100 units tested to 200 units would be $452k, see Table 6. The budget does not include the truck diary surveys as listed in the original solicitation. The truck diary survey can be added to the scope of work.

Table 6 shows option 1 with 200 travel diaries and 50 GPS loggers. Several other combinations of ECM, GPS, and travel diaries can be considered and discussed with ARB if needed.

## Co-funding

SCAQMD is interested in this research and may want to co-fund this work to expand the scope. We are sharing this proposal with them for consideration. We also have a working relationship with EPA through a contract path through the Eastern Research Group for in-use emissions impacts to the MOVES model. We will solicit this proposal to increase the scope with EPA as well. We also approached the EMA with the interest of additional co-funding, but due to the competitive nature between engine manufactures the EMA was not interested.

Table 5. Total project budget for 100 GPS no travel diaries



Table 6. Optional Task 3 budgets listed by category and overall project cost



**Attachment A**

**Resumes of Key People**







**Appendix A**

**Table A-1. 27 EMFAC2011 T6 and T7 Diesel Vehicle Categories**

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**Appendix B**

Table B-1 Certified hhdd and mhdd diesel engines sold in California equipped with SCR



Table B-2 Certified ub and lhdd diesel engines sold in California equipped with SCR



MY 2010 – 2013 (and expected for 2014 -2015) Navistar engines do not use SCR technology and thus were avoided. Future Navistar engines will roll out with Cummins SCR technology and possibly ECM heat calibration approach for cold temperature exhaust.