# DATA COLLECTION, SAMPLING AND EMISSIONS INVENTORY PREPARATION PLAN FOR SELECTED COMMERCIAL AND INDUSTRIAL EQUIPMENT: PHASE II

## FINAL REPORT

**Prepared for:**

**Texas Commission of Environmental Quality (TCEQ)**

**Prepared by:**

**Eastern Research Group, Inc.**
**Sam Wells**

**August 31, 2005**

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Prepared for:

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# EXECUTIVE SUMMARY

This study addresses the second phase of an effort to estimate equipment populations, activity profiles, and resulting emissions for certain industrial and commercial non-road equipment. This effort focused on characterizing population and activity profiles for the following equipment categories in the DFW non-attainment area:[1]

- Forklifts – Diesel, LPG, and gasoline units were evaluated. This category included modified forklifts such as top-picks, side-picks, and reach stackers. These are all the same general design but the means of securing the load can be different. Gantry cranes were not included because they are considered to be true cranes.
- Transportation Refrigeration Units – These were restricted to truck trailers for use in frozen and refrigerated transport of goods, and are almost exclusively diesel-powered. Portable industrial chillers, heat exchangers, and air conditioning units (e.g., ground support equipment for jetliners) were not included. Small APU engines used for truck cabin cooling were also not included.
- Terminal tractors – These are off-highway trucks used in positioning trailers at transportation terminals. In the DFW area they are limited to intermodal facilities. No airport ground support equipment was included.
- Stationary diesel generators – These are diesel-powered electric generation units less than 500 hp that may be connected to the grid in the Dallas area, or may operate in a stand-by capacity for emergency purposes. A survey targeted facilities using generators for base and peaking power generation, as well as for emergency stand-by applications.

These kinds of sources are more difficult to quantify than traditional sources such as construction, agricultural, or recreational equipment, and in many cases planners use national defaults for the purposes of air quality inventories, which in turn are based upon surrogates such as industrial and commercial employment indices. As noted in the guidance for the NONROAD model, local information gathered through (1) databases, (2) expert interviews, and (3) physical or remote surveys is always preferable to use of national defaults.

[1] Collin, Dallas, Denton, Ellis, Johnson, Kaufman, Parker, Rockwall, and Tarrant counties.

Results from this analysis were used to update the emissions inventory for these different source categories, as well as to provide inventory methods that can be extrapolated to, and adopted by, other regions across the state. The findings from the forklift analysis were specifically extended to the 8-county Houston non-attainment area as well.[2]

***LPG Forklifts***

The NONROAD model defines industrial forklifts as "small wheeled forklifts used for warehouses and other general purposes".[3] This definition is intended to distinguish these vehicles from those used in construction applications, termed "rough terrain forklifts". This diversity in applications makes it potentially difficult to develop a comprehensive activity profile for this source category through a standard survey of end-users.

ERG developed a strategy for quantifying LPG forklift activity using two complementary approaches. First, county-specific sales data were obtained from the Industrial Truck Association (ITA) covering multiple years. These data were then combined with assumptions on equipment scrappage rates to develop an in-use population estimate for the area. Second, forklift activity was estimated using LPG fuel consumption and equipment use estimates obtained through a survey.

Using the ITA data, activity estimates from the surveys, and default scrappage rates from the NONROAD model, in-use equipment population totals were estimated. Default horsepower (hp) distributions were then applied to derive final population estimates for use in the NONROAD model, as shown in Table ES-1. Population estimates are also provided for NONROAD defaults as well.

**Table ES-1. LPG Forklift Equipment Populations, by HP (2005)**

| HP Min | HP Max | DFW-Survey | DFW-NONROAD | HGBA-Survey | HGBA-NONROAD |
|---|---|---|---|---|---|
| 25 | 40 | 1,140 | 767 | 1,230 | 505 |
| 40 | 50 | 2,492 | 1,676 | 2,689 | 1,104 |
| 50 | 75 | 6,963 | 4,682 | 7,514 | 3,084 |
| 75 | 100 | 0^ | 0^ | 0^ | 0^ |
| 100 | 175 | 3,048 | 2,050 | 3,290 | 1,350 |
| 175 | 300 | 15 | 10 | 16 | 7 |
| | ***Total*** | ***13,658*** | ***9,184*** | ***14,739*** | ***6,049*** |

^HP range not included in NONROAD2004 model.

[2] Brazoria, Chambers, Fort Bend, Galveston, Harris, Liberty, Montgomery, and Waller counties.
[3] NONROAD User's Guide Appendices, EPA420-P-02-013, December 2002, p. B-5

ERG developed a phone survey for operators in the DFW area to characterize forklift activity, consisting of the following questions:

- How many LPG-powered forklifts does the company operate?
- What is the size of the forklifts?
- How does the company receive propane (e.g., cylinder exchange, on-site filling from a tank truck)?
- Approximately how much fuel (e.g., number of cylinders, gallons, dollar value) do the company's forklifts use per week? Approximately how many hours per weekday do the company's forklifts operate?
- Approximately how many hours do the company's forklifts operate on Saturdays and Sundays?
- Does the company experience a seasonal variation in forklift use?

Survey responses were obtained from 30 forklift users, operating 129 forklifts. Respondents were given the opportunity to report activity in terms of fuel consumption, hours of equipment use, or preferably both, to facilitate response rates. In addition, respondents were given the flexibility to report fuel consumption and/or activity in a variety of different units, again to minimize non-response rates. In general, fuel consumption data was preferred over equipment activity estimates, since aggregated fuel purchase records are more likely to be readily available and accurately recalled than individual forklift clock hours.

A calculation methodology was developed to estimate overall activity for the range of different reporting units and metrics. Hours per year were then calculated for each unit, combining gallon per year estimates with fleet-average gallons per hour values. Total hours for each respondent were then summed and divided by 129 to estimate average hours per unit per year. Hour estimates were based on fuel consumption estimates when available, and on adjusted hour estimates for the remainder of cases. The resulting industry-average activity value was **1,270 hours per year, substantially lower than the 1,800 hours per year default value in NONROAD**.

Respondents also differentiated their activity estimates between weekday and weekend periods. The reported weekday vs. weekend activity levels were used to update NONROAD's temporal allocation file.

Using the ITA data and survey results, ERG updated the default NONROAD population, activity, growth, temporal and geographic allocation files for both the DFW and HGB areas. The resulting ozone season daily NOx emissions estimates for 2005 are presented in Table ES-2, for both NONROAD default and survey-based cases. Estimates for NOx, CO, CO2, PM10, PM2.5, SO2, and VOC were developed for the 2005 base year, as well as 1999, 2002, and 2009, and provided to the TCEQ in NIF2.0 format for loading into the TexAERS database.

**Table ES-2. LPG Forklift Ozone Season Daily NOx Emissions (2005)**

| | NONROAD | Survey |
|---|---|---|
| HGB | | |
| **BRAZORIA** | **0.54** | **0.68** |
| **CHAMBERS** | **0.05** | **0.25** |
| **FORT BEND** | **0.41** | **0.69** |
| **GALVESTON** | **0.28** | **0.27** |
| **HARRIS** | **6.23** | **14.45** |
| **LIBERTY** | **0.05** | **0.15** |
| **MONTGOMERY** | **0.25** | **0.39** |
| **WALLER** | **0.05** | **0.02** |
| ***HGB Total*** | ***7.86*** | ***16.89*** |
| DFW | | |
| **COLLIN** | **0.91** | **0.63** |
| **DALLAS** | **6.17** | **7.67** |
| **DENTON** | **0.48** | **0.89** |
| **ELLIS** | **0.37** | **1.06** |
| **JOHNSON** | **0.19** | **0.27** |
| **KAUFMAN** | **0.14** | **0.23** |
| **PARKER** | **0.09** | **0.03** |
| **ROCKWALL** | **0.04** | **0** |
| **TARRANT** | **3.56** | **4.87** |
| ***DFW Total*** | ***11.95*** | ***15.66*** |

As expected from the higher population estimates, LPG forklift emission estimates based on ITA and survey data result in higher emissions estimates in both regions. The discrepancy is about 30% for the DFW area, and more than a factor of 2 in the HGB region.

***Transportation Refrigeration Units***

Transportation refrigeration units (TRU), referred to as “AC/Refrigeration” units in the NONROAD model, are typically used in cold or frozen transport truck trailers having small, exclusively diesel-powered engines. Two manufacturers make the chillers and freezer machines for TRU. All are small diesel engines connected to a refrigerator compressor mounted on the front of the trailer. This study focused on articulated “semi” trucks as opposed to smaller trucks that might run a compressor from a power take-off on the truck engine, which is common for small vegetable and fruit haulers. Most of the TRU engines are diesels of approximately 28 horsepower. Although few in number, higher HP units may used in rail applications, but are not used in truck trailer TRU.

TRU population and activity in a given area is difficult to evaluate, because they are small, numerous, and mobile, often being transported several hundred miles in a single day. While local TRU activity involved in "dedicated service" (e.g., scheduled local deliveries from distribution facilities to local grocery stores) can be estimated more directly, the number of TRU coming in from out of the area, or passing through the area, is difficult to quantify.

The Vehicle Inventory and Use Survey (VIUS) conducted by the U.S. Census[4] contains information for insulated, refrigerated truck and trailer units. This information is aggregated to the state level. Therefore, statewide populations are estimated first, and then surrogates such as vehicle miles of travel (VMT) and employment can be used to allocate activity to sub-regions such as the Dallas – Fort Worth area.

The first step in determining TRU activity was to summarize the statewide number of refrigerated units reported in the VIUS. Total VIUS trucks include light-duty and SUV trucks as well, from below 5,000 to above 60,000 GVWR. Next, TRU counts were compared to the NONROAD defaults for Texas. Single-unit TRU were significantly reduced based on a review of recent product offerings. Thus it was estimated that only a third of the single-unit TRU actually have a diesel engine. Also, an additional 5% of the total units (1,000) were assumed for the larger rail TRU. The NONROAD default population file was then updated to reflect the revised population and hp distribution. Finally, the default growth file in NONROAD was modified for TRU assuming a 3% annual growth rate from 1999 onward, consistent with typical VMT growth rates in the region. NONROAD's default spatial allocation method was determined to be reasonable, and was used in this analysis.

Allocation within the DFW region was done using TxDOT's Statewide Analysis Model (SAM), which was manipulated to output agricultural food and beverage metrics. This approach is particularly precise, relying on the commodity flow, link-based analysis incorporated in the SAM. These percentages were then applied to the DFW region totals. Average ozone season daily emissions are shown in Table ES-3.

4 U.S. Census Bureau, 2004, '2002 economic census, vehicle inventory and use survey: Texas,' December 2004

**Table ES-3. Average Ozone Season Weekday Emissions by DFW County, 2001 (Tons/Day)**

| County | VOC | NOx | CO | PM10 |
|---|---|---|---|---|
| Collin | 0.03 | 0.16 | 0.09 | 0.02 |
| Dallas | 0.13 | 0.80 | 0.46 | 0.09 |
| Denton | 0.06 | 0.34 | 0.19 | 0.04 |
| Tarrant | 0.05 | 0.31 | 0.18 | 0.03 |
| | 0.27 | 1.60 | 0.92 | 0.17 |

***Terminal Tractors***

Terminal tractors are off-road trucks used for transporting containerized cargo on trailers, and often are used in conjunction with rubber-tired gantry cranes such as to load containers from trains. They are often found at containership ports and intermodal rail yards. Most terminal tractors have diesel engines between 17 and 210 HP. Since terminal tractors are “captive” at specific yards, they can be quantified fairly accurately simply by surveying their known locations.

As of 2004 there was only one intermodal rail yard operating in the DFW area - the BNSF intermodal facility with 33-yard trucks having approximately 300 HP, each operating about 400 hours per month (4,800 hours per year). However, a new UP intermodal yard was under construction in Dallas County at the time of the survey. At the time this writing, UP officials estimate 30-yard trucks between 200 and 300 HP are now in operation, although reliable activity estimates are not yet available. This information was input into the NONROAD model; the default average of 4,667 hours per year was retained because it was approximately equal to the estimated value of 4,800.

The BNSF facility is located in Tarrant County. Annual emissions calculated using the NONROAD model with revised population data for terminal tractors are reported in Table ES-4 below in tons per day for the 2004 base year.

**Table ES-4. Terminal Tractors, 2004 Daily Emissions, Tons**

| County | CO | NOx | PM10 | PM2.5 | SO2 | VOC |
|---|---|---|---|---|---|---|
| Tarrant | 0.038 | 0.136 | 0.009 | 0.009 | 0.019 | 0.010 |

***Stationary Diesel Generators***

Unlike the other equipment types evaluated for this work order, stationary diesel-powered electric generators are not explicitly included in the NONROAD model. The diesel generator sets (or gensets) included in NONROAD are trailer or skid mounted, and therefore not "stationary" by definition. Gensets in this category are typically used at job-sites to provide power for a range of different needs, such as light-towers, air compressors, welders, and other relatively low power applications.

Stationary generators, on the other hand, are most commonly used for emergency (or "standby") power, and less commonly for base load or peaking electric power generation. In all of these cases generators are used to provide power in lieu of power from the electric grid. Emergency generators are particularly common at hospitals, communications facilities, data banks, water supply and treatment locations, power plants and other industrial sites. Under the right economic conditions, peaking or base-load diesel generator applications could be used by industry as a means of reducing high electricity costs. Alternatively, peaking or base load units may be employed at remote locations when access to grid power is not feasible (e.g., for use at temporary asphalt and concrete batch plants).

The objective of this task was to determine the annual and ozone season daily emissions from small stationary diesel engines operating in the Dallas Ozone non-attainment area counties. The systems of interest are less than 500hp (375kW) – units larger than this require an operating permit from the TCEQ. ERG evaluated previous population and activity estimates for these sources, adjusting the results to account for current operating conditions and practices in the Dallas area. After a detailed assessment of the previous study, ERG developed the following conclusions:

- The equipment population estimates and hp distributions developed for this study were based on a large, representative survey database. The resulting population and hp distributions from this study were reasonable and could be used for the current effort.
- National level activity estimates were adjusted based on local survey results, leading to greatly reduced, more reasonable annual usage estimates (~20 – 50 hour/yr).

- The original equipment population and activity dataset used in the previous study categorized each unit according to the reported "duty-cycle" (base, peak, or stand-by/emergency for stationary units). However, the activity adjustments developed from local survey results were not consistent with the corresponding duty-cycle descriptions. Base, peak, and stand-by units all had similar use rates, leading to the conclusion that most units were actually used in emergency/stand-by applications.

To investigate this conclusion ERG performed a simple analysis of the relative cost of electricity obtained from the grid, and electricity produced by diesel generators in the Dallas region. A simple economic analysis indicates that at a diesel price as low as $1.50 per gallon, the cost of diesel-generated electricity would exceed 15 cents/kWh. With peak electricity rates of approximately 11.6 cents per kWh,[5] this cost exceeds most peak power prices paid by smaller commercial establishments. In fact, evaluating historical retail diesel fuel prices in the Gulf Coast region we find that diesel fuel costs have not been low enough to provide a break-even alternative to the grid since the spring of 2004, assuming constant peak electric rates.[6] This finding illustrates why peak-shaving power generation is not economically viable in today's fuel market. Consistent with this conclusion ERG found no instances of peak shaving during its limited phone surveys in the Dallas area.

The current high cost of diesel makes baseload generation with small engines even less competitive with current electric rates in the area. Consistent with this conclusion, only one true application of island power (baseload) generation was identified in the Dallas area during ERG's survey. In a parallel study for the HARC, ERG found less than 5 such batch plants operating in the Dallas region in the fall of 2005.[7] Therefore while certain circumstances may dictate the need for off-grid power from stationary generators, the actual number of such applications appears to be quite small.

**Based on this assessment, the analysis concluded that the vast majority of stationary diesel generator applications less than 500hp in the Dallas region are used for emergency power alone.** These systems are primarily operated during power outages and routine maintenance tests. Operation during power outages will generally place a high load on the engine. However, the duration of power outages varies annually, with many outages being localized to sub-regions of a metropolitan area. ERG obtained the number of hours of service interruption for the TXU service area for 2004. The average customer experienced 5.9 hours of

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[5] Personal communication, TXU Commercial Business Service Desk, August 2005.
[6] http://tonto.eia.doe.gov/dnav/pet/hist/d200630002m.htm
[7] "Minor Source NOx Inventory of Boilers, Process Heaters, and Stationary Engines, and Gas Turbines," HARC Project H-57-2005.

service interruption over 2004, with about 80% of that amount resulting from one storm event in June. Even assuming that all emergency generators were used at or near full load during service outages, most of these emissions would only have occurred during “atypical” meteorology. Therefore these emissions should not be included in estimating ozone season weekday emissions.

Accordingly, essentially all emissions from stationary diesel generators less than 500 hp occur during monthly testing. The ERG survey found testing and maintenance use estimates between 1 and 4 hours per month. However, these units are generally tested in an *unloaded* condition, leading to a much lower load factor than was used in the previous study.

ERG worked with a diesel engine expert at the University of Texas to develop an estimate of “engine load” at idle for this calculation.[8] The effective engine load at idle was determined using an empirically derived equation involving several engine specifications. ERG collected specification data for 42 common makes and models of diesel generators. Assuming the broad range of makes and models identified by ERG is representative the in-use fleet of engines, an effective load factor of 0.11 can be used to replace the previous load factor of 0.74.

ERG used the previous estimates of the population and capacity of diesel generators operating in each county in the Dallas area to estimate emissions. Load factor was reduced to the effective idle load of 0.11 for all units. Ozone season daily estimates were derived from annual estimates by dividing by 365. Table ES-5 presents the resulting annual and ozone season daily emission estimates for each county in the Dallas non-attainment region.

[8] Dr. Ron Matthews, Head, Engines Research Program, Mechanical Engineering Department, University of Texas October 2005.

**Table ES-5. Stationary Diesel Generator Emissions in the Dallas Non-Attainment Region (2004)**

| | TPY | | | TPD | | |
|---|---|---|---|---|---|---|
| County | **PM10** | **NOx** | **VOC** | **PM10** | **NOx** | **VOC** |
| Tarrant | 2.6 | 37.0 | 3.0 | 0.0072 | 0.101 | 0.0082 |
| Rockwall | 0.1 | 1.7 | 0.1 | 0.0003 | 0.005 | 0.0004 |
| Parker | 0.1 | 0.7 | 0.1 | 0.0001 | 0.002 | 0.0002 |
| Kaufman | 0.1 | 1.1 | 0.1 | 0.0002 | 0.003 | 0.0002 |
| Johnson | 0.1 | 1.3 | 0.1 | 0.0003 | 0.004 | 0.0003 |
| Ellis | 0.1 | 1.8 | 0.1 | 0.0003 | 0.005 | 0.0004 |
| Denton | 0.6 | 8.4 | 0.7 | 0.0016 | 0.023 | 0.0019 |
| Dallas | 4.9 | 68.8 | 5.6 | 0.0134 | 0.188 | 0.0153 |
| Collin | 1.2 | 16.2 | 1.3 | 0.0032 | 0.044 | 0.0036 |
| **Total** | **9.7** | **137.0** | **11.1** | **0.0267** | **0.375** | **0.0304** |

Even assuming the higher hours of operation for "peaking" and "base load" units from the previous study, **the revised load factors lower the previous 9-county Dallas area NOx total from 2.29 tons per day to 0.38 tons per day.**

# 1.0 INTRODUCTION

This study addresses the second phase of an effort to estimate equipment populations, activity profiles, and resulting emissions for certain industrial and commercial non-road equipment. The sources evaluated in this study include:

- Industrial forklifts
- Transportation refrigeration units (TRU)
- Terminal tractors (yard trucks)
- Stationary diesel powered electric generators (< 500hp)

These kinds of sources are more difficult to quantify than traditional sources such as construction, agricultural, or recreational equipment, and in many cases planners use national defaults for the purposes of air quality inventories, which in turn are based upon surrogates such as industrial and commercial employment indices. As noted in the guidance for the NONROAD model, local information gathered through (1) databases, (2) expert interviews, and (3) physical or remote surveys is always preferable to use of national defaults.

The methods and approaches developed for these source categories were outlined in an Inventory Preparation Plan (IPP), developed under Phase I of the current study. This report describes ERG's execution of the IPP, along with any required modifications, and the resulting emission inventory estimates for these sources.

## 2.0 BACKGROUND

ERG conducted several subtasks in order to execute the Data Collection and Inventory Development Plan developed under Phase I of this effort. This effort focused on characterizing population and activity profiles for the following equipment categories in the DFW non-attainment area:[9]

- Forklifts – Diesel, LPG, and gasoline units were evaluated. This category included modified forklifts such as top-picks, side-picks, and reach stackers. These are all the same general design but the means of securing the load can be different. Gantry cranes were not included because they are considered to be true cranes.
- Transportation Refrigeration Units – These were restricted to truck trailers for use in frozen and refrigerated transport of goods, and are almost exclusively diesel-powered. Portable industrial chillers, heat exchangers, and air conditioning units (e.g., ground support equipment for jetliners) were not included. Small APU engines used for truck cabin cooling were also not included.
- Terminal tractors – These are off-highway trucks used in positioning trailers at transportation terminals. In the DFW area they are limited to intermodal facilities. No airport ground support equipment was included.
- Stationary diesel generators – These are diesel-powered electric generation units less than 500 hp that may be connected to the grid in the Dallas area, or may operate in a stand-by capacity for emergency purposes. A survey targeted facilities using generators for base and peaking power generation, as well as for emergency stand-by applications.

Results from this analysis were used to update the emissions inventory for these different source categories, as well as to provide inventory methods that can be extrapolated to, and adopted by, other regions across the state. The findings from the forklift analysis were specifically extended to the 8-county Houston non-attainment area as well.[10]

[9] Collin, Dallas, Denton, Ellis, Johnson, Kaufman, Parker, Rockwall, and Tarrant counties.
[10] Brazoria, Chambers, Fort Bend, Galveston, Harris, Liberty, Montgomery, and Waller counties.

## 2.1 Data Collection Objectives

The main objective of this effort was to estimate the ***number of engines by type and size*** operating in the study area. Equipment counts were grouped into "bins" of similar horsepower ranges for use in the NONROAD model. The NONROAD horsepower groupings are:

- 16-25
- 25-40
- 40-50
- 50-75
- 75-100
- 200-150
- 150-300
- 300-600
- 600-750
- 750-1000

***Annual hours of use*** is also required, since emissions are a function of an emission factor, horsepower, and average hours of operation. For use in NONROAD, annual hours of operation are averaged by equipment type and fuel type, independent of the horsepower groupings listed above. For example, the LPG forklift category might have an average usage level of 875 hours per year, regardless of size. Since annual hours data is difficult to obtain, survey responses for this information may be limited and/or relatively uncertain. Therefore one must make an engineering judgment whether any new survey information obtained is significantly different from the default values in NONROAD. Note that this can become problematic especially with equipment categories such as electrical generator sets (gensets), which may be used continuously throughout the year or only for emergency backup.

***Temporal and spatial allocation*** factors allow for equipment populations and activity to be distributed by area (e.g., county), and time of week and season. Growth factors also allow the model to account for increases or decreases in equipment purchases over time. Such data is often obtainable through surveys or readily available surrogates.

***Other variables*** include load factor, engine age distribution, and useful life. In general, it is best to avoid significant modifications to *load factor* settings, which require complex engine testing – operator estimates alone are not reliable. One exception to this rule is when equipment must standby at idle for prolonged periods of time (e.g., standby generators that provide power intermittently). Also, when reliable fuel consumption, activity, and useful life information is available, corresponding load factor may be deduced from standard algorithms.

The *model year distribution* is a difficult parameter to estimate because most survey respondents do not have this information readily available. If even age data is obtained there is no NONROAD input that the user can access. This is because the NONROAD model is "hard coded" as to the distribution of model years. To overcome this difficulty requires either (a) a change to the model source code or (b) use of the by-model-year output, which is then manipulated such as with SAS™ or equivalent statistical data tool, as the files are quite large.

Finally, the *useful life* of an engine usually cannot be determined with adequate certainty from limited surveys, given the vast array of different end-users involved. However, industry sales data and manufacturer experts can often provide reliable estimates of useful life for entire engine categories.

Once appropriate data have been collected through operator surveys, surrogate development, or expert input, the associated NONROAD model files can be revised accordingly to reflect local conditions. NONROAD can then be used to generate locally-specific emission estimates for any specified scenario year. ERG used the modified NONROAD files to estimate base and future year emissions for all but the diesel generator equipment categories, as discussed in detail below.[11]

[11] Modified AP-42 factors were used to estimate diesel generator emissions, due to the unusual operating conditions for these engines, as discussed in Section 3.

# 3.0 DATA COLLECTION AND EMISSION CALCULATION

## 3.1 Industrial Forklifts

***Background***

The NONROAD model defines industrial forklifts as "small wheeled forklifts used for warehouses and other general purposes".[12] This definition is intended to distinguish these vehicles from those used in construction applications, termed "rough terrain forklifts". While a typical industrial forklift application may raise and lower goods on two "forks", there are at least a dozen variants of the design, including:

- Container top-picks
- Container side-picks
- Elevated stack-reach equipment (telescoping boom with forks)

Industrial forklifts may also be fueled or powered by diesel, gasoline, propane (LPG), or electrical batteries. According to the Industrial Truck Association (ITA), which compiles statistics on forklift orders and shipments, approximately 54% of all forklifts sold in the U.S. in 2004 were electric. Of the non-electric (internal combustion) units, 85% were powered by LPG, with 13% powered by diesel, and the remaining 2% by gasoline.[13] These fractions are quite close to the NONROAD default population values (85% for LPG, 10% for diesel, and 5% for gasoline). Given the great preponderance of LPG fueled engines in this category, LPG forklifts were chosen as the focus of this study.

LPG forklifts are commonly used in indoor environments, often preferred over diesel-powered units due to their much lower PM emissions. LPG forklift applications are diverse, covering a wide range of Standard Industrial Classification (SIC) codes, including warehousing, production, and transportation services. This diversity in applications makes it potentially difficult to develop a comprehensive activity profile for this source category through a standard survey of end-users. Therefore ERG initially developed an inventory strategy for these sources

[12] NONROAD User's Guide Appendices, EPA420-P-02-013, December 2002, p. B-5
[13] ITA data purchase, June 2005. *Confidential ITA data – do not distribute or cite.*

designed to focus on the relatively small number of LPG fuel providers. The initial inventory methodology developed by ERG, along with subsequent modifications, is described below.

### 3.1.1 Methodology

During Phase I of this study, ERG developed a strategy for quantifying LPG forklift activity using two complementary approaches.[14] First, county-specific sales data would be obtained from the ITA covering multiple years. These data would then be combined with assumptions on scrappage rates to develop an in-use population estimate for the area. Second, forklift activity would be quantified using LPG fuel consumption estimates obtained through a fuel provider survey. In this way more complicated end-user surveys could be avoided.

ERG completed an initial "pre-test" survey of LPG retailers in the region, identified through Yahoo Yellow Pages, to determine what fraction serve forklift customers, delivery options offered, and whether or not they would be willing to participate in a follow-up survey. The initial survey results indicated this approach was feasible. Once reliable estimates of the amount of fuel consumed by forklifts in the area were developed, actual hours per year of activity could then be back-calculated using brake-specific fuel consumption estimates for these engines.

The following provides a detailed description of the data sources, calculation methods, and assumptions used to estimate forklift populations and activity profiles for the 9-county DFW and 8-county Houston-Galveston-Brazoria (HGB) area.

### 3.1.2 Equipment Population Estimation

ERG acquired ITA statistics on forklift orders and shipments, by class of truck and zip code. The ITA data contained the following information:

- County-level shipments of Class 4 and 5 forklifts to operators in the 9-county DFW area, and the 8-county HGB area, for calendar years 1993, 1998 and 2003;

[14] "Data Collection, Sampling, and Emissions Inventory Preparation Plan for Selected Commercial and Industrial Equipment", Eastern Research Group, prepared for TCEQ, August 31, 2004.

- National level 2004 data regarding the split between propane, gas, diesel, and electric forklift sales; and
- The top 10 purchasers statewide, by Standard Industrial Classification (SIC) Code, for Class 4 and 5 forklifts for the 2004 calendar year.

Class 4 and 5 internal combustion forklifts taken together correspond to the industrial forklift classification in the NONROAD model. (A Class 4 forklift is defined as a rider forklift truck, with cabs and seated controls, internal combustion engines, and solid or "cushion" tires. A Class 5 forklift is defined as a rider forklift truck, with cabs and seated controls, internal combustion engines, and pneumatic tires.)

Table 3-1 provides the county-level sales data obtained from ITA, corrected for LPG sales fractions. Table 3-2 lists the top 10 forklift purchasers, by SIC.

**Table 3-1. LPG Forklift Retail Shipments by Year***

| Region | County | 1993 | 1998 | 2003 |
|---|---|---|---|---|
| **DFW** | Collin | 21 | 58 | 48 |
| | Dallas | 586 | 984 | 594 |
| | Denton | 18 | 42 | 70 |
| | Ellis | 34 | 38 | 82 |
| | Johnson | 11 | 12 | 20 |
| | Kaufman | 4 | 27 | 19 |
| | Parker | 9 | 5 | 3 |
| | Rockwall | 6 | 8 | 0 |
| | Tarrant | 282 | 472 | 378 |
| | *DFW total* | *972* | *1,646* | *1,214* |
| | | | | |
| **HGB** | Brazoria | 46 | 47 | 54 |
| | Chambers | 2 | 15 | 20 |
| | Fort Bend | 17 | 25 | 56 |
| | Galveston | 15 | 43 | 22 |
| | Harris | 989 | 1,525 | 1,175 |
| | Liberty | 7 | 2 | 12 |
| | Montgomery | 9 | 21 | 31 |
| | Waller | 3 | 4 | 2 |
| | *HGB total* | *1,089* | *1,684* | *1,373* |

** Confidential ITA data – do not distribute or cite.*

**Table 3-2. Top SIC Codes by Forklift Class (Texas Sales, 2004)***

| Class 4 | | Class 5 | |
|---|---|---|---|
| SIC Code | Description | SIC Code | Description |
| 4225 | General Warehousing | 5211 | Lumber & Other Bldg. Materials |
| 3999 | General Production | 7359 | Equipment Rental & Leasing, NEC^ |
| 5211 | Lumber & Other Bldg. Materials | 5084 | Industrial Machinery and Equipment |
| 2653 | Corrugated & Solid Fiber Boxes | 4225 | General Warehousing |
| 4213 | Trucking Services, except local | 2448 | Wood Pallets and Skids |
| 4789 | Transportation Services, NEC^ | 3999 | General Production |
| 4731 | Arrangement of Transportation of Freight & Cargo | 5399 | Miscellaneous General Merchandise Stores |
| 3089 | Plastics Products, NEC | 5093 | Scrap and Waste Materials |
| 3499 | Fabricated Metal Products, NEC^ | 5031 | Lumber, Plywood and Millwork |
| 7359 | Equipment Rental & Leasing, NEC^ | 5039 | Construction Materials |

* *Confidential ITA data – do not distribute or cite.*

^ *Not elsewhere classified*

In order to estimate in-use equipment populations in the different areas, ERG performed the following steps:

1. County-level sales totals were linearly interpolated using ITA data to estimate sales between 1993 - 1998, and 1998 – 2003.
2. In order to estimate sales in years prior to 1993, and after 2003, ERG performed several calculations:
    a. Growth factors were obtained for the top SIC categories listed in Table 3-2, for each county, from 1990 – 2005, using a version of the REMI model developed for Texas (Regional Economic Models, Inc.) These factors were provided to TCEQ under a separate study.[15] The base year was 2003.
    b. For each SIC group, county-level growth factors were weighted by county census population to obtain area-wide factors for each region. These weighted factors are shown in Appendix C.

[15] Development of County Level Growth Factors, Eastern Research Group, prepared for TCEQ, February 6, 2006.

c. Area-wide growth factors for each SIC were weighted by the relative incidence of each SIC category, for each area. (Relative SIC incidence rates were obtained from the 1997 *Phonedisc USA* – see Section 3.1.3 below for details.)

d. The weighted factors were then summed across SIC groups to obtain area-wide growth factors by year, for the DFW and HGB regions.

e. These factors were then applied to the 1993 and 2003 ITA data to forecast and back-cast sales at the region level. When combined with the linear interpolations between 1993 and 2003, this provided a complete set of sales estimates for the 1990 – 2005 period, as shown in Table 3-3. (Note that applying the REMI-based growth factors to generate sales estimates for the 1994-1997 or 1999-2002 periods results in significant “discontinuities” at the 1993, 1998, and 2003 years for which we have actual data. For this reason ERG chose to use simple interpolations for these years.)

**Table 3-3. Estimated Area-Wide LPG Forklift Sales, DFW & HGB (1990-2005)***

| Year | DFW | HGB |
|---|---|---|
| 2005 | 1,308 | 1,466 |
| 2004 | 1,266 | 1,425 |
| 2003 | 1,214 | 1,373 |
| 2002 | 1,301 | 1,435 |
| 2001 | 1,387 | 1,497 |
| 2000 | 1,474 | 1,559 |
| 1999 | 1,560 | 1,622 |
| 1998 | 1,646 | 1,684 |
| 1997 | 1,512 | 1,565 |
| 1996 | 1,377 | 1,446 |
| 1995 | 1,242 | 1,327 |
| 1994 | 1,107 | 1,208 |
| 1993 | 972 | 1,089 |
| 1992 | 921 | 1,040 |
| 1991 | 872 | 994 |
| 1990 | 827 | 949 |
| **Total** | **19,984** | **21,677** |

* *Confidential ITA data – do not distribute or cite.*

3. The default equipment scrappage curve from NONROAD was obtained to estimate in-use equipment populations in 2005. The scrap curve provides the fraction of total equipment sales still in use for any given model year, as a function of median engine life,

as shown in Table 3-4. Median engine life is defined as the age at which 50% of engines have been scrapped. The default scrap curve assumes that some engines remain in service up to 2 times the median engine life.

**Table 3-4. Default NONROAD Equipment Scrappage Curve**

| Fraction Median Life Used | Percent Scrapped | Fraction Surviving |
|---|---|---|
| 0.0000 | 0 | 1.00 |
| 0.0588 | 1 | 0.99 |
| 0.1694 | 3 | 0.97 |
| 0.2710 | 5 | 0.95 |
| 0.3639 | 7 | 0.93 |
| 0.4486 | 9 | 0.91 |
| 0.5254 | 11 | 0.89 |
| 0.5948 | 13 | 0.87 |
| 0.6570 | 15 | 0.85 |
| 0.7125 | 17 | 0.83 |
| 0.7617 | 19 | 0.81 |
| 0.8049 | 21 | 0.79 |
| 0.8425 | 23 | 0.77 |
| 0.8750 | 25 | 0.75 |
| 0.9027 | 27 | 0.73 |
| 0.9259 | 29 | 0.71 |
| 0.9451 | 31 | 0.69 |
| 0.9607 | 33 | 0.67 |
| 0.9730 | 35 | 0.65 |
| 0.9824 | 37 | 0.63 |
| 0.9794 | 39 | 0.61 |
| 0.9942 | 41 | 0.59 |
| 0.9973 | 43 | 0.57 |
| 0.9990 | 45 | 0.55 |

| Fraction Median Life Used | Percent Scrapped | Fraction Surviving |
|---|---|---|
| 1.0000 | 50 | 0.50 |
| 1.0010 | 55 | 0.45 |
| 1.0027 | 57 | 0.43 |
| 1.0058 | 59 | 0.41 |
| 1.0106 | 61 | 0.39 |
| 1.0176 | 63 | 0.37 |
| 1.0270 | 65 | 0.35 |
| 1.0393 | 67 | 0.33 |
| 1.0549 | 69 | 0.31 |
| 1.0741 | 71 | 0.29 |
| 1.0973 | 73 | 0.27 |
| 1.1250 | 75 | 0.25 |
| 1.1575 | 77 | 0.23 |
| 1.1951 | 79 | 0.21 |
| 1.2383 | 81 | 0.19 |
| 1.2875 | 83 | 0.17 |
| 1.3430 | 85 | 0.15 |
| 1.4052 | 87 | 0.13 |
| 1.4746 | 89 | 0.11 |
| 1.5514 | 91 | 0.09 |
| 1.6361 | 93 | 0.07 |
| 1.7290 | 95 | 0.05 |
| 1.8306 | 97 | 0.03 |
| 1.9412 | 99 | 0.01 |
| 2.0000 | 100 | 0.00 |

4. Using the annual activity estimate developed in a parallel task (see Section 3.1.3), the fraction of median life for each model year was estimated for the 2005 analysis year. For example, given an average use of ~1,200 hours per year (from the activity survey), a median life of 4,500 hours at full load (NONROAD default), and a default load factor of 0.3, 50% of all forklifts are retired after 13 years, while 10% are retired after 20 years.

5. According to an ITA representative,[16] and a service provider familiar with the resale forklift market in the DFW area,[17] the majority of forklifts are likely to be retired after 10 years, and essentially all will be retired after 20 years. This is also consistent with an independent estimate of 15 to 17 years from the Texas Railroad Commission.[18] In order to adjust the in-use population counts to be consistent with industry estimates, ERG decreased the median engine life value used in NONROAD from 4,500 hours to 3,600 hours. (The default load factor of 0.3 was not changed.) This change yielded an in-use population with approximately 50% of 10-year-old units in operation, but only 3% of 19-year-old units, and no 20-year-old units in operation. Table 3-5 shows the estimated in-use equipment populations as a function of age, using the above assumptions.

**Table 3-5. In-Use Equipment Populations, by Region (2005)***

| | | | DFW | | HGA | |
|---|---|---|---|---|---|---|
| **Engine Age** | **Fraction of Median Life** | **Surviving Pop** | **Annual Sales*** | **In-Use Pop** | **Annual Sales*** | **In-Use Pop** |
| 1 | 0.00 | 1 | 1,308 | 1,308 | 1,466 | 1,466 |
| 2 | 0.11 | 0.99 | 1,266 | 1,253 | 1,425 | 1,411 |
| 3 | 0.21 | 0.97 | 1,214 | 1,178 | 1,373 | 1,331 |
| 4 | 0.32 | 0.95 | 1,301 | 1,236 | 1,435 | 1,363 |
| 5 | 0.42 | 0.93 | 1,387 | 1,290 | 1,497 | 1,392 |
| 6 | 0.53 | 0.89 | 1,474 | 1,311 | 1,559 | 1,388 |
| 7 | 0.64 | 0.87 | 1,560 | 1,357 | 1,622 | 1,411 |
| 8 | 0.74 | 0.83 | 1,646 | 1,367 | 1,684 | 1,398 |
| 9 | 0.85 | 0.77 | 1,512 | 1,164 | 1,565 | 1,205 |
| 10 | 0.95 | 0.69 | 1,377 | 950 | 1,446 | 998 |
| 11 | 1.06 | 0.31 | 1,242 | 385 | 1,327 | 411 |
| 12 | 1.16 | 0.23 | 1,107 | 255 | 1,208 | 278 |
| 13 | 1.27 | 0.19 | 972 | 185 | 1,089 | 207 |
| 14 | 1.38 | 0.15 | 921 | 138 | 1,040 | 156 |
| 15 | 1.48 | 0.11 | 872 | 96 | 994 | 109 |
| 16 | 1.59 | 0.09 | 827 | 74 | 949 | 85 |
| 17 | 1.69 | 0.07 | 777 | 54 | 902 | 63 |
| 18 | 1.80 | 0.05 | 729 | 36 | 856 | 43 |
| 19 | 1.91 | 0.03 | 680 | 20 | 809 | 24 |
| 20 | 2.00 | 0 | 632 | - | 763 | 0 |
| | | | **Total** | **13,658** | | **14,739** |

* *Confidential ITA data – do not distribute or cite.*

[16] Garry Cross, Dunaway and Cross, email communication, 10-24-05.
[17] Craig Werthmann, All Pro Industrial Equipment, Inc., personal communication, August, 2005.
[18] Heather Ball, Texas Railroad Commission, email communication, 5-6-2005.

6. For each region equipment populations were summed across model years to obtain in-use totals. Default horsepower (hp) distributions were then applied to derive final population estimates for use in the NONROAD model, as shown in Table 3-6.

**Table 3-6. LPG Forklift Equipment Populations, by HP (2005)**

| HP Min | HP Max | DFW-Survey | DFW-NONROAD | HGBA-Survey | HGBA-NONROAD |
|---|---|---|---|---|---|
| 25 | 40 | 1,140 | 767 | 1,230 | 505 |
| 40 | 50 | 2,492 | 1,676 | 2,689 | 1,104 |
| 50 | 75 | 6,963 | 4,682 | 7,514 | 3,084 |
| 75 | 100 | 0^ | 0^ | 0^ | 0^ |
| 100 | 175 | 3,048 | 2,050 | 3,290 | 1,350 |
| 175 | 300 | 15 | 10 | 16 | 7 |
| | ***Total*** | ***13,658*** | ***9,184*** | ***14,739*** | ***6,049*** |

^HP range not included in NONROAD2004 model.

7. Finally, county-level population allocation based on the 2003 ITA data was used to update the ALO file for use in NONROAD. Table 3-7 provides the relative county-level allocations for each region.

**Table 3-7. County Allocation Factors**

| DFW | | HGB | |
|---|---|---|---|
| County | Fraction | County | Fraction |
| Collin | 4.0% | Brazoria | 4.0% |
| Dallas | 49.0% | Chambers | 1.5% |
| Denton | 5.7% | Fort Bend | 4.1% |
| Ellis | 6.8% | Galveston | 1.6% |
| Johnson | 1.7% | Harris | 85.6% |
| Kaufman | 1.5% | Liberty | 0.9% |
| Parker | 0.2% | Montgomery | 2.3% |
| Rockwall | 0.0% | Waller | 0.1% |
| Tarrant | 31.1% | | |

***Quality Assurance***

Only 2 independent sources of forklift population data were identified for validation purposes. First, NONROAD default LPG forklift population estimates for the DFW and HGB areas in 2005 total 9,184 and 6,049 respectively, substantially lower than those estimated using the ITA data. On the other hand, the Texas Railroad Commission estimated there are up to

45,000 LPG forklifts currently operating in the state.[19] Assuming forklift populations roughly correlate with census figures, approximately 46% of the statewide equipment total would be present in the DFW and HGB areas (~21,000 units). While higher than the NONROAD default values, this estimate is still significantly lower than the 28,000 units estimated using the ITA data for these areas combined.

### 3.1.3 Equipment Activity Estimation

ERG developed a comprehensive list of the propane suppliers in the DFW area based on discussions with the National Propane Gas Association and a review of the *Yahoo* Yellow Pages. This effort produced a list of 34 propane suppliers in the DFW area.

Preliminary screening phone calls were made to the propane suppliers to determine if they provided fuel to forklift users and if they would be willing to participate in a short phone survey. Of the 34 propane suppliers identified in the DFW area, 18 indicated that they provided fuel to propane users. Of the 18 propane suppliers that service forklift users, 11 suppliers indicated that they would be willing to participate in the survey.

ERG developed a short phone survey for the propane suppliers with questions on the approximate volume of propane deliveries to forklift customers in the DFW area, as well as information on fuel cylinders and other activity data. Attachment D contains the survey questions and responses from propane suppliers.

Of the 34 propane suppliers on the contact list, only 4 provided estimates of fuel sales volumes to forklift customers. Given the very low response rate to this key question, ERG developed an alternative strategy to estimate equipment activity through a phone survey of end-users. ERG used the information contained in the 1997 *Phonedisc USA* to identify potential forklift users in the DFW area. The *Phonedisc USA* is a CD-ROM database prepared by DAK Industries that contains listings for U.S. businesses (approximately 7 million). Business listings can be searched using business name, business type (i.e., SIC code), address, and phone number.

[19] Heather Ball, Texas Railroad Commission, email communication, 5-6-2005.

A query of the *Phonedisc* database for the top SIC categories identified by ITA, and the county FIPS codes returned approximately 4,300 businesses in the DFW area.

ERG developed a phone survey for forklift operators included in this list consisting of the following questions:

- How many Class 4 and/or 5 forklifts does the company operate?
- What is the size of the forklifts?
- How does the company receive propane (e.g., cylinder exchange, on-site filling from a tank truck)?
- Approximately how much fuel (e.g., number of cylinders, gallons, dollar value) do the company's forklifts use per week? Approximately how many hours per weekday do the company's forklifts operate?
- Approximately how many hours do the company's forklifts operate on Saturdays and Sundays?
- Does the company experience a seasonal variation in forklift use?

Likely forklift users were randomly selected from the *Phonedisc* database and contacted by phone to determine if they were eligible (i.e., operate Class 4 and/or 5 forklifts) and would be willing to participate in the phone survey. Survey responses were obtained from 30 forklift users. Attachment E provides the survey responses for each of the 30 participants.

Respondents uniformly reported forklift size in terms of lift capacity rather than hp. HP estimates were developed using model information for Clark forklifts, obtained from the "Spec Finder" on EquipmentWatch.com. The following correlations between unit lift capacity and engine hp were found:

- < 4,000 lbs – 39.5 hp
- 4,000 – 8,000 lbs – 46 hp
- > 8,000 lbs – 82 hp

HP assignments were based on the above associations whenever lift capacity was provided. However, of the 129 forklifts reported by the 30 respondents, 59 had no reported value for lift capacity. For these units ERG assigned the modal hp value reported for LPG forklifts in the NONROAD model (59 hp). Table 3-8 summarizes the resulting hp distribution inferred using these assumptions, as well as the NONROAD default distribution.

**Table 3-8. Derived vs. NONROAD Default LPG Forklift HP Distributions**

| HP Min | HP Max | Survey | Default |
|---|---|---|---|
| 25 | 50 | 41% | 27% |
| 50 | 75 | 46% | 51% |
| 75 | 100 | 13% | 0% |
| 100 | 175 | 0% | 22% |

As seen in the Table, NONROAD2004 does not report any LPG forklifts in the 75 – 100 hp range. The obvious error in the default data would need to be corrected before making a one-to-one comparison between the distributions.

Respondents were given the opportunity to report activity in terms of fuel consumption, hours of equipment use, or preferably both, to facilitate response rates. In addition, respondents were given the flexibility to report fuel consumption and/or activity in a variety of different units, again to minimize non-response rates. In general, fuel consumption data was preferred over equipment activity estimates, since aggregated fuel purchase records are more likely to be readily available and accurately recalled than individual forklift clock hours.

The following summarizes the calculation methodology used to develop overall activity estimates, for the range of different reporting units and metrics.

1. Gallons per week or month were converted to gallons per year assuming use 52 weeks and 12 months per year;

2. When consumption was reported in terms of cylinders per unit time, an 8 gallon cylinder was assumed unless otherwise noted;[20]

[20] Approximately 90% of cylinders used by LPG forklifts are 33 lbs (8 gal), with the remainder being 20 and 43 lb cylinders. (Personal communication, AmeriGas representative, August 19, 2005).

3. If pounds of fuel per unit time were reported, the value was converted to gallons using a standard factor of 4.24 pounds LPG per gallon;[21]

4. If dollars of fuel per week were reported, gallons were calculated using the average after-tax retail value of $1.80 per gallon;[22]

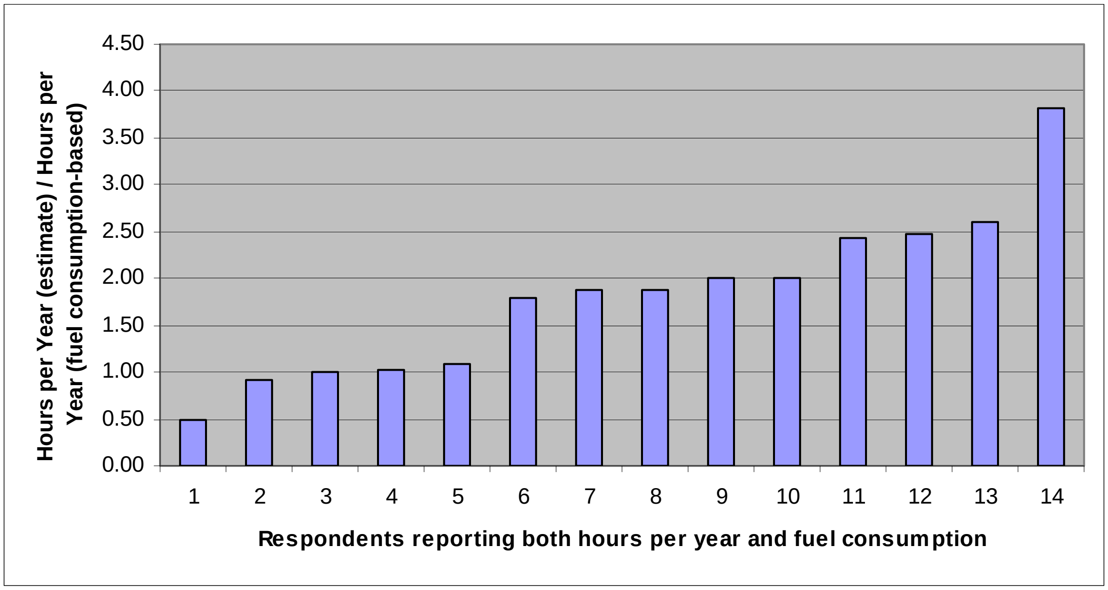
5. Once gallons per year were established for each respondent, an estimate of gallons per hour per unit were calculated using the estimated hp value, along with default brake-specific fuel consumption (0.507 lb/hp-hr) and load factor values (0.3) from NONROAD. A weighted average was developed for fleets with multiple hp values. Fuel consumption was assumed to be distributed equally across all units in a given fleet, in terms of hp-hrs;

6. Hours per year were then calculated for each unit, combining gallon per year estimates with fleet-average gallons per hour values;

7. When available, hour per year estimates derived in this way were compared to hour per year estimates provided directly by respondents. Such paired data was available for 15 of the 30 respondents, accounting for 71 of the 129 forklifts surveyed. The ratio of hours per year reported directly, to hours per year derived from fuel consumption data, was calculated to determine if a systematic bias was apparent in direct reporting. Of the 15 responses with paired data, one apparent "outlier" was identified (with a ratio greater than 3 standard deviations from the mean value). This particular respondent provided an extreme activity estimate, with all 15 forklifts operating "24 hours per day, seven days a week". Dropping this apparent outlier from the data, reported equipment hours were on average 1.8 times higher than the hours derived from fuel consumption estimates, for the remaining 14 respondents with paired data. Figure 3-1 indicates the distribution of this ratio for these 14 respondents.

[21] S. Dakota Fuel Taxation manual -- http://www.state.sd.us/drr2/motorvehicle/motorfuel/manual/lpg_vendor.pdf
[22] Energy Information Administration figure for August 2005, South Region - http://tonto.eia.doe.gov/dnav/pet/pet_pri_top.asp

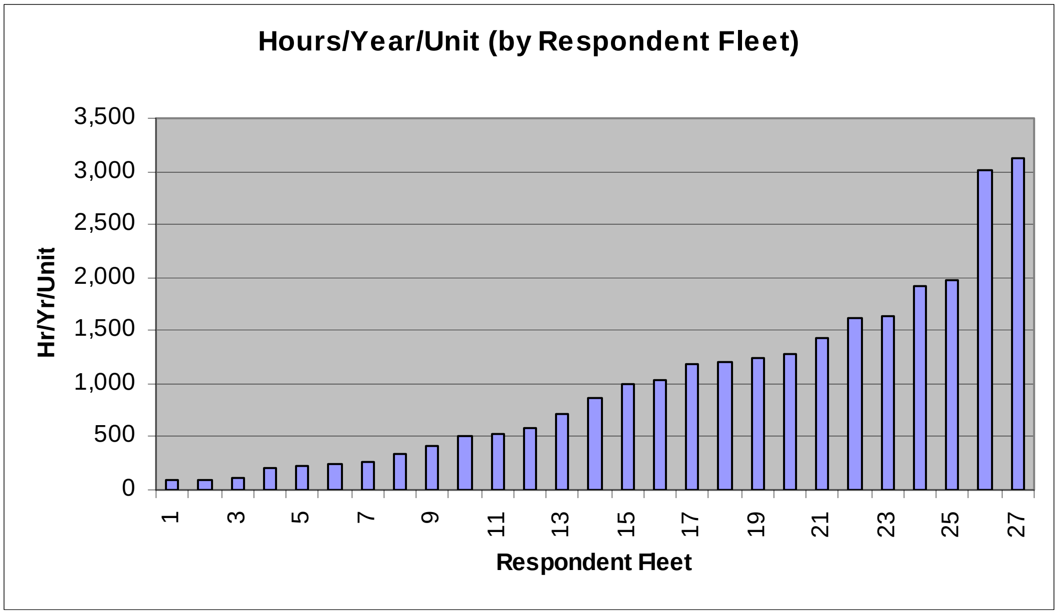
**Figure 3-1. Ratio of Reported Hours/Year to Hours/Year Derived from Fuel Consumption Estimates (by Respondent)**




8. As seen in the figure, 12 of the 14 paired observations are equal to or greater than 1.0. This pattern indicates a clear bias, reflecting a tendency to overestimate hours of operation on the part of the respondent. Assuming that fuel consumption data is more reliable than reported hours of operation, ERG estimated a systematic bias of 1.8 (the average value of the ratio for all forklifts in the paired dataset). ERG used this factor to adjust the hour per year data for those respondents who did not provide fuel consumption estimates. This provided an activity estimate for each of the 129 forklifts (30 respondents).

9. Total hours for each respondent were then summed and divided by 129 to estimate average hours per unit per year. Hour estimates were based on fuel consumption estimates when available, and on adjusted hour estimates for the remainder of cases. The resulting industry-average activity value was **1,270 hours per year, substantially lower than the 1,800 hours per year default value in NONROAD**. Figure 3-2 displays the range of activity estimates derived for the different respondent fleets.

**Figure 3-2. Distribution of Activity Estimates by Respondent Fleet**




10. Respondents differentiated their activity estimates between weekday and weekend periods. Table 3-9 summarizes the reported weekday vs. weekend activity levels, which was used to update NONROAD's temporal allocation file.

**Table 3-9. Reported Weekday vs. Weekend Activity Split**

| | **Weekdays** | **Weekends** |
|---|---|---|
| **Total hr/yr** | 155,647 | 8,199 |
| **fraction** | 0.95 | 0.05 |

***Quality Assurance***

As noted above, the calculated industry-average activity value of 1,270 hours per year was substantially lower than the 1,800 hour per year default value in NONROAD. This difference may be explained in part by the apparent tendency of operators to overestimate hours of operation, as discussed above. Some of the difference may also result from survey sample and/or response bias. During initial research an ITA representative estimated that approximately 90% of forklift deliveries were likely made to operators in the top 10 SIC groupings.[23] Under such a skewed distribution, a random phone survey targeting end-users in just the top SIC

[23] Bill Montwieler, ITA Executive Director, email communication, June 2005.

groupings would likely provide representative results, even if the remaining 10% of forklift operators had very different activity profiles. However, upon receipt of the ITA data, it was found that the top 10 SIC codes were only responsible for approximately 40% of total sales, as opposed to 90%. In addition, ITA reported that 1,019 different 4-digit SIC categories received at least one forklift shipment during 2004, making comprehensive survey coverage of end-users infeasible given available resources.[24] Therefore limiting the survey to the top 10 SIC groupings could potentially bias the resulting activity estimates, to the extent that the non-surveyed SIC groups have substantially different activity profiles. Without activity data from these sources, an assessment of potential bias cannot be made.

On the other hand, to the extent that certain SIC groups are under- or over-represented within the *existing* sample frame, response bias can be assessed, and adjustments can be made. Table 3-10 compares survey response rates with the relative company populations obtained from the *Phonedisc* sample frame. Average hours per year for each SIC group are also provided.

**Table 3-10. Response Bias Assessment**

| SIC group | Hr/Yr/Unit | Responses | Sample |
|---|---|---|---|
| Manufacturing (2000 - 3000) | 2,025 | 25.0% | 8.9% |
| Transport/Utilities (4000) | 977 | 35.7% | 31.6% |
| Wholesale/Retail (5000) | 1,238 | 35.7% | 48.1% |
| Services (7000) | 345 | 3.6% | 11.3% |

As seen in the table, the SIC distribution among survey respondents differs somewhat from the SIC distribution found in the original *Phonedisc* sample frame. Adjusting the response rates by SIC group to correspond to the sample frame distribution, and recalculating the annual hours per year across all SIC groups, we obtain a small adjustment to the previous activity estimate **– 1,124 hr/unit/year, compared to 1,270 hr/unit/year.** ERG concluded that this small adjustment did not warrant re-weighting the final NONROAD population files, given the small impact on emissions.

### 3.1.4 Emissions Estimates

Using the ITA data and survey results described above, ERG updated the default NONROAD population, activity, growth, temporal and geographic allocation files for both the DFW and HGB areas. The resulting ozone season daily NOx emissions estimates for 2005 are presented in Table 3-11, for both NONROAD default and survey-based cases. Estimates for NOx, CO, CO2, PM10, PM2.5, SO2, and VOC were developed for the 2005 base year, as well

[24] Garry Cross, Dunaway and Cross, email communication, 7-22-05.

as 1999, 2002, and 2009, and provided to the TCEQ in NIF2.0 format for loading into the TexAERS database.

**Table 3-11. LPG Forklift Ozone Season Daily NOx Emissions (2005)**

| | NONROAD | Survey |
|---|---|---|
| HGB | | |
| BRAZORIA | 0.54 | 0.68 |
| CHAMBERS | 0.05 | 0.25 |
| FORT BEND | 0.41 | 0.69 |
| GALVESTON | 0.28 | 0.27 |
| HARRIS | 6.23 | 14.45 |
| LIBERTY | 0.05 | 0.15 |
| MONTGOMERY | 0.25 | 0.39 |
| WALLER | 0.05 | 0.02 |
| *HGB Total* | *7.86* | *16.89* |
| | | |
| DFW | | |
| COLLIN | 0.91 | 0.63 |
| DALLAS | 6.17 | 7.67 |
| DENTON | 0.48 | 0.89 |
| ELLIS | 0.37 | 1.06 |
| JOHNSON | 0.19 | 0.27 |
| KAUFMAN | 0.14 | 0.23 |
| PARKER | 0.09 | 0.03 |
| ROCKWALL | 0.04 | 0 |
| TARRANT | 3.56 | 4.87 |
| *DFW Total* | *11.95* | *15.66* |

As expected from the higher population estimates, LPG forklift emission estimates based on ITA and survey data result in higher emissions estimates in both regions. The discrepancy is about 30% for the DFW area, and more than a factor of 2 in the HGB region.

## 3.2 Transportation Refrigeration Units (TRU)

***Background***

Transportation refrigeration units, or TRU, are actually referred to as "AC/Refrigeration" units in the NONROAD model. TRU are typically used in cold or frozen transport truck trailers having small, exclusively diesel-powered engines averaging about 28 HP. Some rail container TRU are higher in HP but are not as numerous.

Two manufacturers make the chillers and freezer machines for TRU: Carrier Transicold and Thermo King.[25] All are small diesel engines connected to a refrigerator compressor mounted on the front of the trailer. This study focused on articulated "semi" trucks as opposed to smaller trucks that might run a compressor from a power take-off on the truck engine, which is common for small vegetable and fruit haulers. According to Gary Macklin of *Refrigerated Transporter*[26] and Bill Webb of the Texas Motor Transportation Association[27] most of the TRU engines are diesels of approximately 28 horsepower. This mean value is consistent with the makes and models available on manufacturer's websites. Although very few in number, higher HP units may used in rail applications, but are not used in truck trailer TRU. The default TRU populations in the NONROAD model, however, indicate that most engines are in the 50 to 70 HP category, with lower counts in the 25 to 40 HP grouping, as shown in Table 3-12.

**Table 3-12. Default TRU Populations in the NONROAD2004 Model**

| HP Min | HP Max | Texas | 4-County DFW |
|---|---|---|---|
| 6 | 11 | 459 | 97 |
| 11 | 16 | 1,412 | 299 |
| 16 | 25 | 1,324 | 280 |
| 25 | 40 | 339 | 72 |
| 40 | 50 | 2,488 | 527 |
| 50 | 75 | 9,569 | 2,027 |
| 75 | 100 | 0 | 0 |
| | *total* | *15,591* | *3,302* |

The EPA Office of Transportation Air Quality was contacted about this discrepancy. EPA did not have any information regarding the HP distributions as provided by Power Systems Research, the provider of the national TRU data in NONROAD. One possible explanation is that Carrier Transicold and Thermo King both make "warehouse-to-warehouse" temporary cold storage units, which are really small area sources rather than true mobile sources, but may be included in the PSR data.

After developing HP distributions, refining TRU activity is the next priority. TRU population and activity in a given area is difficult to evaluate, because they are small, numerous,

[25] Email with Alison Andrews, American Refrigeration Institute, dated May 12, 2004.
[26] Email with Gary Macklin dated 6/24/2004.
[27] Email with Bill Webb dated 8/10/2004

and mobile, often being transported several hundred miles in a single day. While local TRU activity involved in "dedicated service" (e.g., scheduled local deliveries from distribution facilities to local grocery stores) can be estimated more directly, the number of TRU coming in from out of the area, or passing through the area, is difficult to quantify.

According to the USDA and *Driver's Magazine*,[28] approximately 91 percent of chilled and frozen foods are hauled by truck; the remainder is hauled by railroad car. Of the refrigerated truck tonnage, 58 percent is hauled by whole truckload and the remainder is hauled by less-than-truckload (LTL) shipments. Thus the market is fairly complex, including dedicated local service shipments to grocery stores, for-hire contract carriers such as interstate trucking companies, and LTL carriers stocking convenience stores. Dairy suppliers also comprise a significant proportion of the fleet.

Travel models such as the Statewide Analysis Model (SAM) for Texas estimate commodity flows based on trips and vehicle miles of travel (VMT). *If* commodity codes can be correlated with TRU use, then such a travel model could be used to quantify truck trips involving TRU. The SAM contains three commodity codes that would be useful for estimating TRU activity in a given area of Texas: Farm Products (code #01), Fresh Fish or Other Related Marine Products (#09), and Food and Kindred Products (#20). Unfortunately, these codes are very broad and the proportions of loads having a diesel TRU engine are expected to be very low. For example, farm products may include massive shipments of grain, which is not refrigerated; some of the local fish products are shipped on ice; much of the grocery store shipments are dry goods not chilled or frozen. Ultimately, it was not feasible to convert vehicle miles of travel (VMT) to population counts, the latter of which are required for use in the NONROAD model. Therefore a revised methodology was developed, as described below.

### 3.2.1 Revised Methodology

The Vehicle Inventory and Use Survey (VIUS) conducted by the U.S. Census[29] contains information for insulated, refrigerated truck and trailer units. This information is aggregated to the state level. Therefore, statewide populations are estimated first, and then surrogates such as

[28] Drivers, 2001. 'Redefining refrigerated transport,' Sean Kilcarr, December 31, 2001.

VMT and employment can be used to allocate activity to sub-regions such as the Dallas – Fort Worth area. The general process for estimating TRU emissions is as follows:

1. Obtain VIUS data for the most recent truck census. The most recent survey was started in 2001 and published in 2004.
2. Select statewide population counts and VMT for single-unit and tractor-trailer TRU.
3. Adjust the single-unit TRU counts for non-diesel motors on single-unit vans, since some are known to operate hydraulically and do not have separate diesel engines (and are therefore excluded from the NONROAD category).
4. Sum the single-unit and tractor-trailer TRU counts and assign them to the 25-40 horsepower (HP) category used in the NONROAD model. As discussed above, most of the TRU are in the 24-34 HP range, with an average of approximately 28 HP.
5. Increase the number of TRU to include higher HP categories. This can be done by conducting a survey, analyzing nationwide estimates, or using a default of 5 percent for rail containers. These additional TRU should then be assigned to the HP bins in the 40-50 HP or even the 50-75 HP categories found in the NONROAD model.
6. Edit the NONROAD population file for TRU in Texas. The source category code (SCC) for diesel, industrial refrigeration is #2270003060. Ensure that all HP sub-categories not being used are reset to zero. Set the population base year to 2001, corresponding to the VIUS data. Run the model for this SCC only. If data is available, the activity file relating to average number of hours can also be adjusted; for this study, default NONROAD activity was used because of a lack of local data regarding TRU on-time, since refrigerated trucks and trailers do not utilize their TRU engines 100 percent of the time and local VMT data could not be used to estimate annual hours of use.
7. For modeling years other than the base population year, modify the growth (GRW) file using historical and projected truck VMT for the region as available.
8. Allocation to selected counties can be done within the model using defaults, or in post-processing. This topic is discussed at length in later sections dealing with the SAM and other allocation tools.

[29] U.S. Census Bureau, 2004, ‘2002 economic census, vehicle inventory and use survey: Texas,’ December 2004

### 3.2.2 Activity and Emissions Calculations

The first step was to summarize the statewide number of refrigerated units reported in the VIUS, as shown in Table 3-13. Total VIUS trucks include light-duty and SUV trucks as well, from below 5,000 to above 60,000 GVWR.

**Table 3-13. VIUS Estimate of TRU in Texas, 2001-2002**

| Trucks | Number | VMT | VMT/Truck |
|---|---|---|---|
| Single Unit Reefer | 6,500 | 161,200,000 | 24,800 |
| Tractor Trailer Reefer | 12,500 | 1,113,300,000 | 89,064 |
| Reefer Subtotal | 19,000 | 1,274,500,000 | 67,079 |
| Total Texas Trucks | 6,412,000 | 95,175,800,000 | 14,843 |

Next, TRU counts were compared to the NONROAD defaults for Texas, as shown in Table 3-14. Single-unit TRU were significantly reduced based on a review of recent product offerings, as all of Thermo King single units identified were electrically powered, and only about half the Carrier Transicold units were true diesels.[30,31] Thus it was estimated that only a third of the single-unit TRU actually have a diesel engine. Also, an additional 5% of the total units (1,000) were assumed for the larger rail TRU. The NONROAD default population file was then updated to reflect the revised population and hp distribution. (Note that NONROAD assumes the same load factors – 0.43 – and the same emission factors – between 4.9 and 7.1 g/hp-hr, depending on age/emission standard – for all TRU hp bins.)

Finally, the default growth file in NONROAD was modified for TRU assuming a 3% annual growth rate from 1999 onward. The 3% value is consistent with typical VMT growth rates in the region.

[30] http://www.thermoking.com/tk/index.asp
[31] http://www.trucktrailer.carrier.com/generic/0,2804,CLI1_DIV7_ETI9198,00.html

**Table 3-14. Comparison of VUIS and NONROAD Default Statewide TRU Counts**

| HP Min | HP Max | NONROAD Default | VIUS Revision |
|---|---|---|---|
| 6 | 11 | 459 | 0 |
| 11 | 16 | 1,412 | 0 |
| 16 | 25 | 1,324 | 0 |
| 25 | 40 | 339 | 14,645 |
| 40 | 50 | 2,488 | 0 |
| 50 | 75 | 9,569 | 1,000 |
| 75 | 100 | 0 | 0 |
| | *total* | *15,591* | *15,645* |

The resulting statewide emission estimates are shown in Table 3-15, comparing the default and VIUS-based equipment population counts. While the TRU totals shown in Table 3-14 are remarkably similar, the hp distribution is not. As a result of having fewer large engines in the plus-50 HP category, this approach results in lower emissions, as shown in Table 3-15.

**Table 3-15. Comparison of Default and VIUS Methods, 2001 (Tons/Yr)**

| Scenario | VOC | NOx | CO | PM10 |
|---|---|---|---|---|
| Default NONROAD | 400.95 | 2,929.33 | 1,527.69 | 309.13 |
| VIUS | 339.96 | 2,009.43 | 1,159.30 | 218.84 |

***Geographic Allocation***

The NONROAD model uses county population to allocate TRU populations to the county level.[32] The population ratio of the four core DFW counties to Texas as a whole was 21.2%.[33] Vehicle miles of Travel (VMT) was also explored as an independent option for allocating TRU populations to the 4-county region as a whole. Using VMT data from the consolidated emission reporting rule (CERR), this ratio was calculated to be slightly lower using summer VMT estimates for all 254 counties, at 20.5%.[34] Therefore NONROAD's default

[32] EPA, 2004, 'Geographic allocation of state level NONROAD engine population data to the county level, EPA420-P-04-014, April 2004.

[33] Core counties include Collin, Dallas, Denton, and Tarrant.

[34] TCEQ, 2004, 'Technical Note: 2002 Three-Year Cycle Emissions Inventory Methodology for 216 Counties in Texas,' prepared by Texas Transportation Institute, May 2004

allocation method was deemed reasonable, and was used in this analysis. Findings are reported below for both statewide and DFW area emissions in Table 3-16 below.

**Table 3-16. Annual TRU Emissions Allocated to the DFW Region, 2001 (Tons/Yr)**

| Area | VOC | NOx | CO | PM10 |
|---|---|---|---|---|
| Statewide (VIUS-based) | 340 | 2,009 | 1,159 | 219 |
| DFW (using NONROAD Allocation) | 72 | 426 | 246 | 46 |

Allocation within the DFW region was done using the SAM, which was manipulated to output agricultural food and beverage metrics. This approach is particularly precise, relying on the commodity flow, link-based analysis incorporated in the SAM. Relevant NAICS codes are:

- 3114 – Fruit & vegetable & specialty products
- 3115 - Dairy products
- 3116 – Meat products
- 3117 – Seafood products

Table 3-17 summarizes the commodity-specific, VMT percentages at the county-level.

**Table 3-17. Allocation Percentages based on SAM Output VMT, 2001**

| County | VMT | Percent |
|---|---|---|
| Collin | 92,634 | 10.0% |
| Dallas | 460,198 | 49.8% |
| Denton | 193,878 | 21.0% |
| Tarrant | 176,856 | 19.1% |
| | 923,565 | 100.0% |

These percentages were then applied to the DFW totals shown in Table 5. Annual emissions are shown in Table 3-18, and average ozone season daily emissions are shown in Table 3-19. A seasonal adjustment factor of 266 was used to adjust annual emissions to the ozone season daily emissions. This factor assumes TRU usage would be higher in the hotter summertime temperatures, although independent validation would be needed to confirm this estimate.

**Table 3-18. Annual Emissions by DFW County, 2001 (Tons/Yr)**

| County | VOC | NOx | CO | PM10 |
|---|---|---|---|---|
| Collin | 7.22 | 42.69 | 24.63 | 4.65 |
| Dallas | 35.88 | 212.06 | 122.34 | 23.09 |
| Denton | 15.11 | 89.34 | 51.54 | 9.73 |
| Tarrant | 13.79 | 81.49 | 47.02 | 8.88 |
| | 72.00 | 425.57 | 245.53 | 46.35 |

**Table 3-19. Average Ozone Season Weekday Emissions by DFW County, 2001 (Tons/Day)**

| County | VOC | NOx | CO | PM10 |
|---|---|---|---|---|
| Collin | 0.03 | 0.16 | 0.09 | 0.02 |
| Dallas | 0.13 | 0.80 | 0.46 | 0.09 |
| Denton | 0.06 | 0.34 | 0.19 | 0.04 |
| Tarrant | 0.05 | 0.31 | 0.18 | 0.03 |
| | 0.27 | 1.60 | 0.92 | 0.17 |

### 3.2.3 Discussion and Conclusions

This analysis first attempted to use the SAM to directly estimate TRU populations and activity in the DFW region. However, the complex nature of the trucking industry made such an evaluation impractical. Specifically, there are many kinds of trucking companies that haul food and beverage goods in insulated, refrigerated units, such as:

- Dedicated revenue carriers (common to large processors and grocery chains)
- Less than load (LTL) for hire carriers, such as for stocking convenience stores
- Independent haulers, such as for dairies, fish products, and so forth

Without the VIUS data, a very large survey of all carrier types would be needed to determine TRU numbers and annual hours of operation *within the DFW region*. Such a survey would have to target locations trucks are worked and operated, at the state level. We also know that there may be considerable interstate movement of refrigerated goods as well. In addition, Texas TRU trucks traveling out of state could well be balanced by out-of-state TRU trucks operating in Texas. We simply cannot know for certain until a more definitive commodity flow model that explicitly includes refrigeration units is designed and implemented.

Without the benefit of the actual PSR data, one can only speculate about the high numbers of small as well as high-powered TRU diesel engines, as seen in the NONROAD default data. Extensive research shows that there is little in the way of diesel engines below 28 HP, as most new TRU diesels are 34 HP, and a few intermodal TRU used on rail containers are slightly higher. Smaller engines are single-unit TRU, powered by a power take-off from the truck's engine, so there is no separate diesel engine dedicated to cooling. If a truck survey is conducted in Texas in the future, it is recommended that TRU be reported by truck/trailer configuration, such as by DOT survey codes, since the smaller, non-articulated configurations will all be powered from the drive engine and not a separate TRU.

Rail TRU containers are particularly difficult to quantify, but are still thought to reflect less than 5 percent of the weight and dollar value of refrigerated goods in the DFW area. Initial investigation into rail activities showed that some truck trailers are transported by rail and that their auxiliary TRU diesel engines may in fact be used in transit. In addition, some refrigerated goods may be carried in specially-designed railcars having larger TRU, but these are thought to be rare or low in density because rail TRU spend so little time in the area. For example, refrigerated goods may be shipped by rail to Los Angeles and then shipped to Japan, especially commodities such as fresh seafood, so there is little time of operation within Texas.

Due to these uncertainties, further studies are recommended to address intermodal TRU operations in Texas, including refrigerated air transport.

## 3.3 Terminal Tractors

Terminal tractors are the most easily quantified of the equipment categories evaluated in this study. Terminal tractors are off-road trucks used for transporting containerized cargo on trailers, and often are used in conjunction with rubber-tired gantry cranes such as to load containers from trains. They are often found at containership ports and intermodal rail yards. Most terminal tractors have diesel engines between 17 and 210 HP. Since terminal tractors are "captive" at specific yards, they can be quantified fairly accurately simply by surveying their known locations.

As of 2004 (the base year for this analysis) there was only one intermodal rail yard operating in the DFW area - the BNSF intermodal facility with 33-yard trucks having approximately 300 HP, each operating about 400 hours per month (4,800 hours per year).[35] However, a new UP intermodal yard was under construction in Dallas County at the time of the survey. At the time this writing, UP officials estimate 30-yard trucks between 200 and 300 HP are now in operation, although reliable activity estimates are not yet available.[36] (Note that ERG has modified the NONROAD growth files accounting for this increase in terminal tractors in the region, starting in 2005.)

This information was input into the NONROAD model; the default average of 4,667 hours per year was retained because it was approximately equal to the estimated value of 4,800.

***Results***

The BNSF facility is located in Tarrant County. Annual emissions calculated using the NONROAD model with revised population and activity data for terminal tractors are reported in Table 3-20 below in tons per year for the 2004 base year. Since these facilities operate almost every day of the year, continuously; daily emissions were derived by dividing annual totals by 365, and are shown in Table 3-21.

**Table 3-20. Terminal Tractors, 2004 Annual Emissions, Tons**

| County | CO | NOx | PM10 | PM2.5 | SO2 | VOC |
|---|---|---|---|---|---|---|
| Tarrant | 12.09 | 42.75 | 2.90 | 2.82 | 6.07 | 3.13 |

[35] Eastern Research Group , "Heavy-Duty Vehicle Idle Activity and Emission Characterization Study," prepared for TCEQ, August 31, 2004.

**Table 3-21. Terminal Tractors, 2004 Daily Emissions, Tons**

| County | CO | NOx | PM10 | PM2.5 | SO2 | VOC |
|---|---|---|---|---|---|---|
| Tarrant | 0.038 | 0.136 | 0.009 | 0.009 | 0.019 | 0.010 |

## 3.4 Stationary Diesel Generators

***Background***

Unlike the other equipment types evaluated for this work order, stationary diesel-powered electric generators are not explicitly included in the NONROAD model. The diesel generator sets (or gensets) included in NONROAD are trailer or skid mounted, and therefore not "stationary" by definition. Gensets in this category are typically used at job-sites to provide power for a range of different needs, such as light-towers, air compressors, welders, and other relatively low power applications.

On the other hand, stationary generators are most commonly used for emergency (or "standby") power, and less commonly for base load or peaking electric power generation. In all of these cases generators are used to provide power in lieu of power from the electric grid. Emergency generators are particularly common at hospitals, communications facilities, data banks, water supply and treatment locations, power plants and other industrial sites. Under the right economic conditions, peaking or base-load diesel generator applications could be used by industry as a means of reducing high electricity costs. Alternatively, peaking or base load units may be employed at remote locations when access to grid power is not feasible (e.g., for use at temporary asphalt and concrete batch plants).

### 3.4.1 Survey Methodology

The objective of this task was to determine the annual and ozone season daily emissions from small stationary diesel engines operating in the Dallas Ozone non-attainment area counties that are used to produce electric power. The systems of interest are less than 500hp (375kW) – units larger than this require an operating permit from the TCEQ. These units may be used to

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[36] Personal Communication with Wint Marler, Facilities Manager, Dallas Intermodal Terminal, Union Pacific Railroad, January 19, 2006.

provide: ***emergency*** power; "***electric-island***" power where a facility provides their own power, independent of the electric grid; and ***peak-shaving*** power to offset peak electric rates.

***Data Sources and Survey Instrument***

The first effort under this task was to contact TXU Electric Delivery Services, the local electric power distribution utility; the Electric Reliability Council of Texas (ERCOT); the local natural gas suppliers; the local fire departments; and the local municipal planning departments, to collect any data they may have on small engines use in the area. If any of these sources had a listing or database of businesses that are known to use engines for generating electric power, ERG was to conduct a survey of these businesses to collect the information necessary to estimate emissions from these engines.

As noted above, stationary generators less than 500 hp in size do not require an operating permit. Therefore there is no comprehensive database of small stationary generators operating in the Dallas area. However, ERG identified a limited number of partial databases of engine owners who were likely to operate engines in this size range, and could be surveyed about their diesel generator use and activity levels. This activity data could then be used to estimate emissions in the Dallas area. These databases included:

- Dallas Planning Department database, including diesel fuel tank installation permits (35)
- Fort Worth Planning Department, including electric generator hook-up permits (40)
- Texas Comptroller's Office list of persons filing diesel fuel tax refund claims (65)

Each of these sources was contacted to obtain potential information for the survey. The Planning Department and the Comptroller's Office databases contained tens of thousands of permit records or entries each. However, upon detailed review it was determined that only a small fraction of the permit and tax refund claim records contained direct references to fuel tank installation, generator hook-ups, and/or "utility" refund claims. The number of relevant entries identified in each database is noted above, for a total of 140 possible survey candidates.

ERG requested contact names and phone numbers for each of these survey candidates. Next, a phone survey script was developed to capture engine population and activity data, and approved by TCEQ for use (see Appendix A). The survey requested information on the following for use in emissions estimation:

- Size (kW or hp)
- Hours of operation in 2004 (hours)
- Fuel type (diesel or dual fuel with natural gas)
- Estimated load factor (% full load, or qualitative answer)
- Year it was installed (can be very approximate), and
- Use of engine –
    - during outages (w/ the exception of running the engine a few hr/mo for maintenance purposes)
    - daily operations (i.e. no electricity close to site)
    - during periods of high electric rates
    - farming/ranching/agricultural purposes
    - to start other engines and turbines
    - Testing the engine for research purposes

Finally, if the engine was used for generating electric power during electrical outages, the survey asked how many of the operating hours were for routine maintenance and how many hours were for actual emergency generation. Respondents were also asked if there was a load put on the engine during the routine maintenance, or was the engine at idle.

### 3.4.2 Survey Results

As stated, the three databases identified yielded 140 potential owners/operators of engine-generator sets. These 140 entities were surveyed by telephone to obtain information about their use of small diesel engine-generator sets using the phone survey script described above.

Of the 140 potential owners/operators, 79 sites responded to the survey questions. Of the 79 respondents, 22 respondents, or 28%, owned or operated approximately 100 diesel engine-generator sets less than 500hp.  This equates to an average of 6 engines per site.  All but 1 of the diesel engine-generator sets was used for emergency power generation.  The other diesel engine generator set was used for base load power.  Only two sites reported having duel fuel capability; reporting that they used natural gas as a back-up to diesel fuel.

The one base load diesel generator identified in the survey was used to power a portable batch concrete plant.  The unit had a capacity of 330hp and burned 1,924 gallons of diesel fuel in 2004.

The 32 emergency diesel generators that reported size data ranged from 27hp to 460hp, and averaged 180hp.  These generators were operated on routine test cycles ranging from 1 hr/month to 1 hr/week, to ensure their readiness for emergency generation.  Nine of the generator sets reported annual fuel usage, which averaged 86 gal/engine-yr.  Two respondents (municipalities) operated 41 emergency generators.

***Quality Assurance of Survey Findings***

A detailed review of the survey participants was then performed to determine if the respondent pool represented a reasonable cross-section of likely operators of stationary generators.   Of the 100 engines identified in the survey, 63% were operated by municipalities. The remaining 37% were operated by a range of end-users, including construction contractors, waste management companies, and assorted commercial companies.

Several key equipment users were not represented in the respondent pool, including public health facilities and airports, which *are required by code* to have electrical back-up capacity installed in case of emergencies.  Other significant users of back-up generators including public schools were also not included in the respondent list.  Accordingly ERG concluded that the databases used to compile the survey sample frame were not robust or representative enough of actual equipment operators to be used as a basis for estimating equipment populations. (Generators that were not included in the three databases may have been installed without the proper permits, or installed under some form of comprehensive building permit, which does not identify the presence of specific equipment, such as diesel engines.)

To supplement the findings of the phone survey described above, ERG obtained an alternative sample frame used in a previous survey effort.[37] The contact information provided in this sample frame included respondents from a recent survey in 2004, indicating ownership or operation of at least one stationary diesel generator in the Dallas study area. 50 contacts were selected from the overall list to investigate the feasibility of using this listing as an alternative sample frame.

Upon contact, ERG asked to speak with someone in "facilities maintenance" or "facilities engineering", or someone responsible for the maintenance and operation of their electrical generation equipment. However, after repeated attempts ERG only identified one generator owner. Rather than pursue the previous call list any further, ERG decided to investigate alternative methods for estimating activity levels for these engines.

### 3.4.3 Adjustments to Available Activity Estimates

As an alternative to the phone survey methodology, ERG evaluated previous population and activity estimates for this source category, adjusting the results to account for current operating conditions and practices in the Dallas area. Specifically, ERG reviewed the 2004 Dallas area inventory estimates developed by ENVIRON for the Houston Advanced Research Center (HARC) and the TCEQ.[9] After a detailed assessment of this study, ERG developed the following conclusions:

- The equipment population estimates and hp distributions developed for this study were based on a large, representative survey database. Equipment counts and distribution across SICs developed at the national level, and allocated to the Dallas region, were verified independently through an additional survey of local owner/operators. Accordingly we believe the resulting population and hp distributions from this study were reasonable and could be used for the current effort.

[37] ENVIRON International, "Estimates of Emissions for Small-Scale, Stationary Diesel Generator Engines in the Dallas-Fort Worth Area," TERC Project H-10 / TCEQ Project 108, September 28, 2004.

- National level activity estimates were adjusted based on local survey results, leading to greatly reduced, more reasonable annual usage estimates. The activity estimates for engines less than 500 hp (~20 – 50 hour/yr) were quite similar to the values found in ERG's limited survey.
- The original equipment population and activity dataset used in the ENVIRON study was developed by Power Systems Research (PSR). PSR categorized each unit identified during its survey according to the "duty-cycle" reported by the respondent (base, peak, or stand-by/emergency for stationary units).[38] However, the activity adjustments developed from local survey results were not consistent with the corresponding duty-cycle descriptions. Namely, while "emergency" units had average annual use rates of 20 to 30 hours per year, "baseload" units had annual usage rates of approximately 45 hours per year. By definition these units cannot be used in true baseload operations. Peak shaving units had similar use rates, *leading us to believe that most units were actually being used in emergency/stand-by applications.*

To investigate this conclusion ERG performed a simple analysis of the relative cost of electricity obtained from the grid, and electricity produced by diesel generators in the Dallas region. Before electricity deregulation, some peak shaving units were installed in the Dallas area. About 80% of them were diesel-fired and 20% were natural gas-fired. However since deregulation, there aren't any incentive programs from the utility companies for generating peak-shaving power. Even when utilities offered peak shaving incentives, the participating companies would only operate their generators for the minimum requirement of 100 hours. Some participating companies managed to obtain their incentives without operating their generators.[39]

A simple economic analysis indicates that at a diesel price as low as $1.50 per gallon, the cost of diesel-generated electricity would exceed 15 cents/kWh. With peak electricity rates of approximately 11.6 cents per kWh,[40] this cost exceeds most peak power prices paid by smaller commercial establishments. In fact, evaluating historical retail diesel fuel prices in the Gulf

[38] PSR may have made certain adjustments to these categories depending on the reported annual hours of use, although the frequency of any adjustments is not cited in the report.
[39] Personal communication, Scott Thomas, Senior Technical Representative, Cummins Southern Plains Power, July 2005.
[40] Personal communication, TXU Commercial Business Service Desk, August 2005.

Coast region we find that diesel fuel costs have not been low enough to provide a break-even alternative to the grid since the spring of 2004, assuming constant peak electric rates.[41] This finding illustrates why peak-shaving power generation is not economically viable in today's fuel market. Consistent with this conclusion ERG found no instances of peak shaving during its limited phone surveys in the Dallas area.

The current high cost of diesel makes baseload generation with small engines even less competitive with current electric rates in the area. Consistent with this conclusion, only one true application of island power (baseload) generation was identified in the Dallas area during ERG's survey. This application was a portable batch concrete plant, which moved locations too frequently to justify the electrical hook-up fees associated with using local electric power. In a parallel study for the HARC, ERG found less than 5 such batch plants operating in the Dallas region in the fall of 2005.[42] Therefore while certain circumstances may dictate the need for off-grid power from stationary generators, the actual number of such applications appears to be quite small.

(Another exception to this pattern might be large plants which can generate power on a large scale, and which can use the waste heat from power generation for process operations. However, these "co-generation" systems will generally be larger than 500hp.)

After concluding that the vast majority of engines previously labeled "baseload" and "peak shaving" were almost certainly used solely in emergency back-up applications, ERG reviewed the PSR database development methodology once again to identify possible reasons for this inconsistency. First the PSR data on equipment populations were based on national surveys from 2003, a time when diesel fuel costs were substantially lower than today. Accordingly, there may have been certain regions of the country where diesel-generated electricity was actually competitive with peak electricity costs at that time.

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[41] http://tonto.eia.doe.gov/dnav/pet/hist/d200630002m.htm
[42] "Minor Source NOx Inventory of Boilers, Process Heaters, and Stationary Engines, and Gas Turbines," HARC Project H-57-2005.

In addition, PSR's methodology uses the national average incidence rates by SIC group, along with SIC counts by region, to allocate engine populations to the local level. However, the methodology does not account for relative differences in regional diesel and electricity prices, which are all-important determinants of fuel switching practices. As such, their approach may inadvertently assign peak and baseload generators to regions of the country with unfavorable economics for these activities, such as Dallas.

Table 3-22 summarizes the revised equipment totals by hp grouping, for each county in 2004, assuming all stationary units identified in the previous study are used in emergency applications.

**Table 3-22. Stationary Diesel Generators < 500 hp (9-County Region, 2004)**

| County | 0 - 25 hp | 25 - 50 hp | 50 - 100 hp | 100 – 250 hp | 250 – 500 hp | Total |
|---|---|---|---|---|---|---|
| Collin | 186 | 961 | 487 | 660 | 186 | **2,294** |
| Dallas | 758 | 3,610 | 1,980 | 2,734 | 2,080 | **2,480** |
| Denton | 107 | 549 | 267 | 334 | 266 | **2,480** |
| Ellis | 24 | 178 | 62 | 72 | 52 | **2,480** |
| Johnson | 21 | 137 | 46 | 48 | 39 | **2,480** |
| Kaufman | 19 | 119 | 39 | 40 | 32 | **2,480** |
| Parker | 15 | 102 | 29 | 28 | 19 | **2,480** |
| Rockwall | 24 | 169 | 54 | 64 | 50 | **2,480** |
| Tarrant | 417 | 2,014 | 1,082 | 1,520 | 1,128 | **2,480** |
| ***Total*** | ***1,571*** | ***7,839*** | ***4,046*** | ***5,500*** | ***3,852*** | ***22,134*** |

### *Load Factor Adjustments*

This analysis concluded that the vast majority of stationary diesel generator applications less than 500hp in the Dallas region are used for emergency power alone. These systems are primarily operated during power outages and routine maintenance tests. Operation during power outages will generally place a high load on the engine, and we believe the load factor of 0.74 used in the previous analysis to be reasonable for this application.

However, the duration of power outages varies annually, with many outages being localized to sub-regions of a metropolitan area. ERG obtained the number of hours of service interruption for the TXU service area for 2004.[43] The average customer experienced 5.9 hours of service interruption over 2004, with about 80% of that amount resulting from one storm event in June. Even assuming that all emergency generators were used at or near full load during service outages, most of these emissions would only have occurred during "atypical" meteorology. Therefore these emissions should not be included in estimating ozone season weekday emissions.

Based on these conclusions, essentially all emissions from stationary diesel generators less than 500 hp occur during monthly testing. The ERG survey found testing and maintenance use estimates between 1 and 4 hours per month, corresponding well with the values reported by ENVIRON of ~20 – 30 hours per year. However, these units are generally tested in an *unloaded* condition, leading to a much lower load factor than was used in the previous study.[44]

ERG worked with a diesel engine expert at the University of Texas to develop an estimate of "engine load" at idle for this calculation.[45] The standard definition of engine load refers to the power output of the engine itself. However, at idle power output goes to zero, leading to an unrealistic emissions estimate (i.e., zero emissions at idle). Therefore the load factor used in the emission calculation had to be renormalized to account for an engine's frictional loses at idle, which must be overcome to keep the pistons moving. The effective engine load at idle was determined using an empirically derived equation, discussed in detail in Appendix B. The calculation involves several engine specifications, including rated hp, cylinder pressure (in kiloPascals), stroke (in mm), idle revolutions per minute (RPM), and displacement (in liters). ERG collected this data for 42 common makes and models of diesel generators, as

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[43] TXU Service Quality Report to the Public Utility Commission of Texas, 2004.
[44] A very small fraction of standby units may be tested using "full/partial load" simulators, but their number is estimated to be insignificant by equipment vendors (Scott Thomas, Cummins Southern Plains Power, July 2005).
[45] Dr. Ron Matthews, Head, Engines Research Program, Mechanical Engineering Department, University of Texas October 2005.

shown in Table 3-23.[46] The derived frictional hp values are also shown, along with the effective load factor, defined as the ratio of frictional and brake hp (FHP/BHP).

### Table 3-23. Common Diesel Generator Engine Specifications

| Make | Model | kW | HP | P (kPa) | Stroke (mm) | RPM | Disp (ltrs) | FHP-idle | FHP/BHP |
|---|---|---|---|---|---|---|---|---|---|
| Daewoo | D1146 | 85 | 114 | 4250 | 139 | 1500 | 8.1 | 20.1 | 0.177 |
| Daewoo | D1146T | 118 | 158 | 4250 | 139 | 1500 | 8.1 | 20.1 | 0.127 |
| Daewoo | P086TI | 199 | 267 | 4250 | 139 | 1500 | 8.1 | 20.1 | 0.075 |
| Daewoo | P126TI-II | 294 | 394 | 4250 | 155 | 1500 | 11.05 | 29.9 | 0.076 |
| Daewoo | P158LE | 414 | 555 | 4250 | 142 | 1500 | 14.6 | 36.9 | 0.066 |
| Cummins | 4B3.9-G2 | 38 | 51 | 4250 | 120 | 1500 | 3.92 | 8.7 | 0.171 |
| Cummins | 4B3.9-G3 | 52 | 70 | 4250 | 120 | 1500 | 3.92 | 8.7 | 0.125 |
| Cummins | 4B3.9-G4 | 61 | 82 | 4250 | 120 | 1500 | 3.92 | 8.7 | 0.107 |
| Cummins | 6BT5.9-G6 | 104 | 139 | 4250 | 120 | 1500 | 5.9 | 13.1 | 0.094 |
| Cummins | 6CT8.3-G2 | 130 | 174 | 4250 | 135 | 1500 | 8.3 | 20.2 | 0.116 |
| Cummins | 6CTA8.3-G2 | 175 | 235 | 4250 | 135 | 1500 | 8.3 | 20.2 | 0.086 |
| Cummins | LTA10-G3 | 238 | 319 | 4250 | 136 | 1500 | 10 | 24.4 | 0.077 |
| Cummins | NT855-G6 | 301 | 403 | 4250 | 152 | 1500 | 14 | 37.3 | 0.092 |
| Cummins | NTA855-G4 | 341 | 457 | 4250 | 152 | 1500 | 14 | 37.3 | 0.082 |
| Volvo | TD520GE | 83 | 111 | 4250 | 130 | 1500 | 4.76 | 11.2 | 0.101 |
| Volvo | TAD520GE | 96 | 129 | 4250 | 130 | 1500 | 4.76 | 11.2 | 0.087 |
| Volvo | TD720GE | 124 | 166 | 4250 | 130 | 1500 | 7.15 | 16.9 | 0.102 |
| Volvo | TAD720GE | 145 | 194 | 4250 | 130 | 1500 | 7.15 | 16.9 | 0.087 |
| Volvo | TAD721GE | 179 | 240 | 4250 | 130 | 1500 | 7.15 | 16.9 | 0.070 |
| Volvo | TAD722GE | 197 | 264 | 4250 | 130 | 1500 | 7.15 | 16.9 | 0.064 |
| Volvo | TAD740GE | 242 | 324 | 4250 | 135 | 1500 | 7.28 | 17.7 | 0.055 |
| Volvo | TAD940GE | 265 | 355 | 4250 | 138 | 1500 | 9.36 | 23.1 | 0.065 |
| Volvo | TAD941GE | 311 | 417 | 4250 | 138 | 1500 | 9.36 | 23.1 | 0.056 |
| Volvo | TAD1241GE | 354 | 474 | 4250 | 150 | 1500 | 12.13 | 32.0 | 0.067 |
| Volvo | TAD1242GE | 387 | 519 | 4250 | 150 | 1500 | 12.13 | 32.0 | 0.062 |
| Vamo | D2500G | 24.2 | 32 | 4250 | 127 | 1500 | 2.5 | 5.8 | 0.179 |
| Vamo | D3900G | 41.6 | 56 | 4250 | 127 | 1500 | 3.9 | 9.1 | 0.162 |
| Perkins | 403C-11G | 9.4 | 13 | 4250 | 81 | 1500 | 1.13 | 1.9 | 0.152 |
| Perkins | 403C-15G | 13.3 | 18 | 4250 | 90 | 1500 | 1.49 | 2.7 | 0.152 |
| Perkins | 404C-22G | 20.4 | 27 | 4250 | 100 | 1500 | 2.21 | 4.3 | 0.158 |
| Perkins | 3.1524 | 27.7 | 37 | 4250 | 127 | 1500 | 2.5 | 5.8 | 0.156 |
| Perkins | 1004G | 44 | 59 | 4250 | 127 | 1500 | 3.99 | 9.3 | 0.157 |
| Perkins | 1004TG1 | 64 | 86 | 4250 | 127 | 1500 | 3.99 | 9.3 | 0.108 |
| Perkins | 1104C-44TAG1 | 78 | 105 | 4250 | 127 | 1500 | 4.41 | 10.2 | 0.098 |
| Perkins | 1006TG1A | 91.5 | 123 | 4250 | 127 | 1500 | 5.99 | 13.9 | 0.113 |
| Perkins | 1104C-44TAG2 | 98 | 131 | 4250 | 127 | 1500 | 4.41 | 10.2 | 0.078 |
| Perkins | 1006TAG | 133.5 | 179 | 4250 | 127 | 1500 | 5.99 | 13.9 | 0.078 |
| Perkins | 2306C-E14TAG1 | 304 | 407 | 4250 | 165 | 1500 | 14.6 | 41.5 | 0.102 |
| Perkins | 2306C-E14TAG2 | 344 | 461 | 4250 | 165 | 1500 | 14.6 | 41.5 | 0.090 |

[46] http://www.allworlddieselgen.com/pricelist.html

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Perkins | 2306C-E14TAG3 | 387 | 519 | 4250 | 165 | 1500 | 14.6 | 41.5 | 0.080 |
| Andoria | 4C90MG03 | 18.6 | 25 | 4250 | 95 | 1500 | 2.42 | 4.6 | 0.183 |
| Andoria | 6CT107-2/E7/2 | 106 | 142 | 4250 | 120 | 1500 | 6.54 | 14.6 | 0.102 |
| FHP (idle) = Frictional HP at Idle | | | | | | | | ***Average*** | ***0.106*** |

Assuming the broad range of makes and models indicated above is representative the in-use fleet of engines, an effective load factor of 0.11 can be used to replace the previous load factor of 0.74.

***Emission Estimation***

ERG obtained the working files from the previous HARC study. The spreadsheet files contained estimates of the population and capacity of diesel generators operating in each county in the Dallas area, broken out by kW range and duty cycle. ERG first converted kW values to hp using the standard conversion factor of 1.341 kW/hp, adjusting the equipment count groupings accordingly. Only equipment less than 500 hp was retained for this analysis. Next the AP-42 emission factors expressed in lb/MWh (applicable to engines < 600hp) were converted to lb/1000 HP-hr. These values are summarized below in Table 3-24.

**Table 3-24. Emission Factors for Diesel Generators < 600 HP (lb/1,000 HP-hr)**

| NOx | PM-10 | VOC |
|---|---|---|
| 30.9 | 2.2 | 2.5 |

ERG retained the annual activity estimates developed for the previous study (20 – 32 hr/yr for units designated “emergency”, and ~45 hr/hr of units designated “peaking” and “baseload”). Load factor was reduced to the effective idle load of 0.11 for all units, however.

The hp, activity, emission factor, and load factor values for each unit can be combined linearly to estimate emissions, according to the following equation:

*Emissions = [Capacity(HP)]**[Activity (hr/yr)]*[1/1000]*[EF (lb/1000HP-hr)]*[1ton/2000lb]*load factor*

Ozone season daily estimates were derived from annual estimates by dividing by 365. Table Z presents the resulting annual and ozone season daily emission estimates for each county in the Dallas non-attainment region.

**Table 3-25. Stationary Diesel Generator Emissions in the Dallas Non-Attainment Region (2004)**

| | TPY | | | TPD | | |
|---|---|---|---|---|---|---|
| County | **PM10** | **NOx** | **VOC** | **PM10** | **NOx** | **VOC** |
| Tarrant | 2.6 | 37.0 | 3.0 | 0.0072 | 0.101 | 0.0082 |
| Rockwall | 0.1 | 1.7 | 0.1 | 0.0003 | 0.005 | 0.0004 |
| Parker | 0.1 | 0.7 | 0.1 | 0.0001 | 0.002 | 0.0002 |
| Kaufman | 0.1 | 1.1 | 0.1 | 0.0002 | 0.003 | 0.0002 |
| Johnson | 0.1 | 1.3 | 0.1 | 0.0003 | 0.004 | 0.0003 |
| Ellis | 0.1 | 1.8 | 0.1 | 0.0003 | 0.005 | 0.0004 |
| Denton | 0.6 | 8.4 | 0.7 | 0.0016 | 0.023 | 0.0019 |
| Dallas | 4.9 | 68.8 | 5.6 | 0.0134 | 0.188 | 0.0153 |
| Collin | 1.2 | 16.2 | 1.3 | 0.0032 | 0.044 | 0.0036 |
| **Total** | **9.7** | **137.0** | **11.1** | **0.0267** | **0.375** | **0.0304** |

Even assuming the higher hours of operation for “peaking” and “base load” units from the previous study, **the revised load factors lower the previous 9-county Dallas area NOx total from 2.29 tons per day to 0.38 tons per day**.

Finally, note that actual emergency operations may or may not have been included in the survey estimates of hours of use per year. This analysis assumed that actual emergency operation hours were not included in the annual use estimates. Netting these hours out of the annual totals would further reduce emissions between 10 and 20%.

# Appendix A

## Phone Survey Script for Stationary Diesel Generator Survey

Good morning / afternoon, I would like to speak with (get name from excel file) . [If they are not available], I'd like to speak with someone who is familiar with the natural gas and diesel engines that are located at your (location of facility from excel file) facility.

***[Introduction]***
Let me just quickly tell you what we are doing. My name is __________. I am with Eastern Research Group. We are working for the Texas Commission on Environmental Quality to confirm and update their data on diesel engines located in the greater Dallas and Fort Worth areas. Our records show that you have ___ engines located at the ________ address. Is this information correct, or have there been changes to the equipment you are using?

For each engine we want to confirm the following 8 pieces of information (complete the confirmation for one engine before going to the next engine; share with them the data we know):

1- Size (kW),
2- Hours of operation in 2004 (hours),
3- Fuel type(diesel or nat. gas),
4- Load factor (% full load, or qualitative answer),
5- Year it was installed (can be very approximate),
6- Use of engine-
  - a- Generating electric power only **during outages** (w/ the exception of running the engine 4 hr/mo for maintenance purposes)
  - b- Generating electric power for **daily operations** (i.e. no public electricity close to site)
  - c- Generating electric power during periods **of high electric rates** (i.e. mid afternoons in the summer months)
  - d- Generating electric power for **farming/ranching/agricultural** purposes,
  - e- Generating electric power used to **start other engines and turbines**,
  - f- Testing the engine for **research** purposes.

7- If the engine was used for generating **electric power during electrical outages** (option 6a above), how many of the operating hours were for routine maintenance and how many hours for actual emergency generation? AND was there a load put on the engine during the routine maintenance, or was the engine just idled?

[If they have questions about our study they may contact Steve Anderson at TCEQ 512-239-1246, so that they can follow up with Steve. However, ask them if they would please confirm whatever data they know while you have them on the phone. If they plan to talk to Steve, let him know they will be calling. Try to leave it that you will call them back at an opportune time of their choosing, if they want to talk with Steve first.]

# Appendix B

## Estimating Effective Load Factors for Diesels at Idle

The equation normally used to calculate annual emissions of species i from an engine is:

$$AE_i = BHP_{rated}[hp] \times activity[hr/yr] \times EF_i[g_i/hp-hr] \times LF \qquad (1)$$

where $EF_i$ is the emission factor for species i and LF is the load factor. Logically, the load factor at idle should be 0.0, since the load factor is a linear scaling of the rated brake power. However, this procedure would yield an annual emission rate of 0.0 even for an engine that idled 24/7. To overcome this difficulty, the load factor in Equation 1 can be posed as:

$$AE_i = BHP_{rated}[hp] \times activity[hr/yr] \times EF_i[g_i/hp-hr] \times \left\{ \frac{IHP_{rated}}{BHP_{rated}} LF' \right\} \qquad (2)$$

where $IHP_{rated}$ is the indicated horsepower (the power available at the top of the piston, prior to frictional and parasitic losses) that corresponds to the rated brake power and LF' is the load factor based on indicated power. Although the brake power is zero at idle, the indicated power is not. Thus, Equation 2 rescales the calculation of annual emissions to reference the indicated power rather than the brake power. For idle operation, LF' can be calculated from:

$$LF' = \frac{IHP_{idle}}{IHP_{rated}} \qquad (3a)$$

At idle, all of the indicated power is used to overcome frictional and parasitic losses. That is, at idle, the indicated power equals the friction power:

$$LF' = \frac{IHP_{idle}}{IHP_{rated}} = \frac{FHP_{idle}}{IHP_{rated}} \qquad (3b)$$

The Chen-Flynn (1965) correlation for diesel engine friction can be used to determine the friction power at idle:

$$FHP_{idle} = \left[13.79 + 0.005P_{max}^{idle} + 2.715*10^{-4}(2SN_{idle})\right] \times \left(DN_{idle}/x\right) \times \frac{1.341}{60000} \qquad (4)$$

where $P_{max}$ is the maximum cylinder pressure (at idle) in kPa, S is the stroke in mm, $N_{idle}$ is the idle speed in rpm, D is the engine displacement in liters, and x is the number of revolutions per intake stroke (2 for a 4-stroke engine, 1 for a 2-stroke), and the last term is a collection of conversion factors to yield power in horsepower (HP). Gary Neely of Southwest Research Institute cited that the maximum cylinder pressure idle is typically 4000-4500 kPa, so a value of 4250 kPa should be used in Equation 4.

The mechanical efficiency of an engine is the efficiency of overcoming frictional and parasitic losses:

$$\eta_m \equiv \frac{BHP}{IHP} \tag{5a}$$

Under rated operating conditions, this becomes:

$$\eta_m^{rated} \equiv \frac{BHP_{rated}}{IHP_{rated}} \tag{5b}$$

Therefore, Equation 2 becomes:

$$AE_i = BHP_{rated} \times activity \times EF_i \times \left\{ \frac{1}{\eta_m^{rated}} \frac{FHP_{idle}}{BHP_{rated} / \eta_m^{rated}} \right\} \tag{6a}$$

Canceling the mechanical efficiency terms yields:

$$AE_i = BHP_{rated} \times activity \times EF_i \times \left\{ \frac{FHP_{idle}}{BHP_{rated}} \right\} \tag{6b}$$

<u>Reference</u>

Chen, S.K., and P.F. Flynn (1965), "Development of a single cylinder compression ignition test engine", SAE Paper 650733.

# SIC-Specific REMI Growth Factors Used in Forklift Sales Projections

DFW Region

| SIC Code | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 244 | 0.6559 | 0.695564 | 0.711902 | 0.791813 | 0.899655 | 0.907731 | 0.970534 | 0.971003 | 1.055403 | 1.049712 | 1.003592 | 0.981941 | 0.992477 | 1 | 1.033329 | 1.048174 |
| 265 | 0.877537 | 0.885494 | 0.96746 | 0.990008 | 1.000981 | 1.147709 | 1.122067 | 1.015551 | 1.034674 | 1.081927 | 1.071952 | 1.007501 | 1.004057 | 1 | 1.028931 | 1.036004 |
| 308 | 0.623582 | 0.59324 | 0.632407 | 0.67921 | 0.734939 | 0.785533 | 0.816388 | 0.879682 | 0.933341 | 0.993856 | 0.996931 | 0.969778 | 0.980175 | 1 | 1.057421 | 1.095061 |
| 349 | 0.522024 | 0.528895 | 0.540143 | 0.570512 | 0.624212 | 0.679385 | 0.702376 | 0.745634 | 0.810246 | 0.884362 | 1.002367 | 0.974257 | 0.981269 | 1 | 1.062581 | 1.097326 |
| 399 | 0.754564 | 0.75049 | 0.800596 | 0.736938 | 0.814495 | 0.834506 | 0.906032 | 0.899763 | 0.99705 | 0.987082 | 0.96889 | 0.96447 | 0.970127 | 1 | 1.052527 | 1.082948 |
| 421 | 0.470877 | 0.46473 | 0.5203 | 0.553369 | 0.597312 | 0.623146 | 0.673225 | 0.734873 | 0.820728 | 0.906831 | 0.964421 | 0.962531 | 0.977181 | 1 | 1.046159 | 1.086562 |
| 422 | 0.470877 | 0.46473 | 0.5203 | 0.553369 | 0.597312 | 0.623146 | 0.673225 | 0.734873 | 0.820728 | 0.906831 | 0.964421 | 0.962531 | 0.977181 | 1 | 1.046159 | 1.086562 |
| 473 | 0.785391 | 0.697162 | 0.698198 | 0.740737 | 0.793966 | 0.929125 | 0.959685 | 1.023664 | 0.942416 | 0.958665 | 1.003595 | 0.97542 | 0.984779 | 1 | 1.050237 | 1.09334 |
| 478 | 0.785391 | 0.697162 | 0.698198 | 0.740737 | 0.793966 | 0.929125 | 0.959685 | 1.023664 | 0.942416 | 0.958665 | 1.003595 | 0.97542 | 0.984779 | 1 | 1.050237 | 1.09334 |
| 503 | 0.589347 | 0.59985 | 0.622396 | 0.674267 | 0.712009 | 0.753191 | 0.775597 | 0.819521 | 0.878732 | 0.932104 | 1.009906 | 0.972727 | 0.9867 | 1 | 1.047861 | 1.083268 |
| 508 | 0.589347 | 0.59985 | 0.622396 | 0.674267 | 0.712009 | 0.753191 | 0.775597 | 0.819521 | 0.878732 | 0.932104 | 1.009906 | 0.972727 | 0.9867 | 1 | 1.047861 | 1.083268 |
| 509 | 0.589347 | 0.59985 | 0.622396 | 0.674267 | 0.712009 | 0.753191 | 0.775597 | 0.819521 | 0.878732 | 0.932104 | 1.009906 | 0.972727 | 0.9867 | 1 | 1.047861 | 1.083268 |
| 521 | 0.657532 | 0.656846 | 0.675935 | 0.687545 | 0.735217 | 0.736259 | 0.767758 | 0.782225 | 0.810325 | 0.894711 | 0.990048 | 0.976232 | 0.988086 | 1 | 1.023774 | 1.048198 |
| 539 | 0.657532 | 0.656846 | 0.675935 | 0.687545 | 0.735217 | 0.736259 | 0.767758 | 0.782225 | 0.810325 | 0.894711 | 0.990048 | 0.976232 | 0.988086 | 1 | 1.023774 | 1.048198 |
| 735 | 0.666112 | 0.661123 | 0.631843 | 0.664245 | 0.707022 | 0.770791 | 0.801245 | 0.819257 | 0.894155 | 0.947869 | 0.980931 | 0.979298 | 0.984292 | 1 | 1.040274 | 1.075656 |

HGB Region

| SIC Code | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 244 | 0.591283 | 0.593408 | 0.662722 | 0.698324 | 0.729856 | 0.810726 | 0.828436 | 0.820565 | 0.989992 | 0.917806 | 0.978326 | 1.012072 | 0.998904 | 1 | 1.018924 | 1.027783 |
| 265 | 0.657475 | 0.688673 | 0.785842 | 0.788702 | 0.907829 | 0.934379 | 1.025534 | 0.955202 | 1.009805 | 1.025876 | 1.034354 | 1.013553 | 1.001856 | 1 | 1.019904 | 1.028329 |
| 308 | 0.584878 | 0.552814 | 0.628553 | 0.742976 | 0.832152 | 0.823347 | 0.923406 | 0.925293 | 0.976575 | 0.940141 | 0.98773 | 0.984214 | 0.985994 | 1 | 1.0475 | 1.077897 |
| 349 | 0.51579 | 0.557892 | 0.615022 | 0.623636 | 0.648063 | 0.701824 | 0.765773 | 0.846921 | 0.92891 | 0.915819 | 1.002446 | 0.993002 | 0.988836 | 1 | 1.05101 | 1.07668 |
| 399 | 0.606987 | 0.684972 | 0.613942 | 0.622679 | 0.673834 | 0.739202 | 0.831651 | 0.92101 | 0.88351 | 0.898922 | 0.945707 | 0.98999 | 0.974635 | 1 | 1.042428 | 1.066798 |
| 421 | 0.606976 | 0.638524 | 0.679624 | 0.698602 | 0.727093 | 0.740192 | 0.764282 | 0.817871 | 0.929778 | 0.933022 | 0.963792 | 0.975986 | 0.981488 | 1 | 1.041521 | 1.07672 |
| 422 | 0.606976 | 0.638524 | 0.679624 | 0.698602 | 0.727093 | 0.740192 | 0.764282 | 0.817871 | 0.929778 | 0.933022 | 0.963792 | 0.975986 | 0.981488 | 1 | 1.041521 | 1.07672 |
| 473 | 0.569987 | 0.549749 | 0.616729 | 0.65607 | 0.654107 | 0.738118 | 0.731585 | 0.779926 | 0.88215 | 0.934508 | 0.955797 | 0.957857 | 0.975528 | 1 | 1.0557 | 1.103947 |
| 478 | 0.569987 | 0.549749 | 0.616729 | 0.65607 | 0.654107 | 0.738118 | 0.731585 | 0.779926 | 0.88215 | 0.934508 | 0.955797 | 0.957857 | 0.975528 | 1 | 1.0557 | 1.103947 |
| 503 | 0.624704 | 0.656074 | 0.681638 | 0.713642 | 0.737317 | 0.780386 | 0.817255 | 0.877278 | 0.937987 | 0.967292 | 1.008386 | 0.989769 | 0.991329 | 1 | 1.042447 | 1.072798 |
| 508 | 0.624704 | 0.656074 | 0.681638 | 0.713642 | 0.737317 | 0.780386 | 0.817255 | 0.877278 | 0.937987 | 0.967292 | 1.008386 | 0.989769 | 0.991329 | 1 | 1.042447 | 1.072798 |
| 509 | 0.624704 | 0.656074 | 0.681638 | 0.713642 | 0.737317 | 0.780386 | 0.817255 | 0.877278 | 0.937987 | 0.967292 | 1.008386 | 0.989769 | 0.991329 | 1 | 1.042447 | 1.072798 |
| 521 | 0.640556 | 0.640987 | 0.667554 | 0.699082 | 0.735271 | 0.749636 | 0.759811 | 0.770139 | 0.821124 | 0.899258 | 0.982139 | 0.989403 | 0.991682 | 1 | 1.017721 | 1.035538 |
| 539 | 0.640556 | 0.640987 | 0.667554 | 0.699082 | 0.735271 | 0.749636 | 0.759811 | 0.770139 | 0.821124 | 0.899258 | 0.982139 | 0.989403 | 0.991682 | 1 | 1.017721 | 1.035538 |
| 735 | 0.911654 | 0.830314 | 0.746365 | 0.777303 | 0.828361 | 0.861054 | 0.871054 | 0.883261 | 0.946696 | 0.957618 | 0.9954 | 1.010074 | 0.990983 | 1 | 1.03758 | 1.066925 |

**Summary of Phone Survey Responses from Propane Suppliers**

| Company | Response to Phone Survey Questions[a] | | |
|---|---|---|---|
| | Question 1 | Question 2 | Question 3 |
| 1 | Left message with vmail. | | |
| 2 | Left message with vmail. | | |
| 3 | Manager said that they sell approximately 4,000,000 gallons/yr to forklift users in the DFW area. | He said it is about a 50/50 mix of cylinders and bobtail truck deliveries. Cylinder size varies but most of the forklifts are 30,000 lb lifts. | Not really. The forklifts typically have a fuel gauge/alarm that says when the tank is empty. |
| 4 | Declined to participate in survey | | |
| 5 | Left a message with vmail. | | |
| 6 | Said she had no idea of the volume but she would try to get back to me. | 8 gallons is their standard size | Usually the cylinders are empty but there might be a little left sometimes (they do refund for any remaining gas) |
| 7 | For all types of customers, the company sells 7,585 gal/day (this number is representative of daily sales). Most of there customers are forklift users. | 33 lb | Usually the cylinders are empty but there might be a little left sometimes (there may be some left but the forklifts can't run on the little bit remaining). |
| 8 | Manager out. | | |

| Company | Response to Phone Survey Questions[a] | | |
|---|---|---|---|
| | Question 1 | Question 2 | Question 3 |
| 9 | Said a very rough guess would be approximately 30,000 gal/yr. The company is a small distributor and they don't keep track of who their customers are. | 30 lb | Not really |
| 10 | Company is a high-volume marketer. They do not have bobtail trucks and they do not sell to any forklift users that they know of. | | |
| 11 | Company does not supply propane. | | |
| 12 | Left vmail. | | |
| 13 | Neither contact were in. | | |
| 14 | Said a rough estimate is approximately 500,000 gal/yr. | The size of the bottles varies. | They fill cylinders on-site so they do not keep track of any gas remaining in the cylinders. |
| 15 | Invalid phone number in TX white pages. | | |
| 16 | Phone goes directly to answering machine (left vmail). | | |
| 17 | Company does not supply propane. | | |
| 18 | Company does not supply propane (only equipment and service). | | |
| 19 | Invalid phone number in TX white pages. | | |
| 20 | No such company (or any with similar name) in TX white pages. | | |
| 21 | No such company (or any with similar name) in TX white pages. | | |

| Company | Response to Phone Survey Questions[a] | | |
|---|---|---|---|
| | Question 1 | Question 2 | Question 3 |
| 22 | Company does not supply propane (only equipment and service). | | |
| 23 | Left vmail. | | |
| 24 | They do sell propane but they have no idea of how much goes to forklift users or any other types of customers. | | |
| 25 | Phone rings but there is no answer (machine or human). | | |
| 26 | Manager out. | | |
| 27 | Approximately 700 gallons per week to forklift users (54 bottles per truck (bottles filled twice per day (three days a week the bottles are filled 3 times)) | 8 gallons | Bottles are always empty. |
| 28 | Company does not supply propane (only equipment and service). | | |
| 29 | Company purchased by another.  Operator directed me to prior contact. | | |
| 30 | Company does not supply propane (only equipment and service). | | |
| 31 | Company does not supply propane. | | |
| 32 | Phone rings but no answer (machine or human) - eventually goes to busy signal. | | |
| 33 | They have no idea of the volume sold to forklift users (or any particular users really).  They just fill bottles that customers bring in (no deliveries).  Size of cylinders range from 5 - 25 lb. | | |
| 34 | Same as other location (they have no idea - only fill cylinders that are brought in by customers).  Size of cylinders range from 5 - 25 lb. | | |

[a]The following questions are asked of the companies surveyed:

- Question 1 - What is the approximate volume of propane deliveries to forklift customers in the Dallas/Fort Worth area?
- Question 2 - Are the forklift cylinders a standard size(s)?
- Question 3 - When the company receives the used cylinders back from their customers, in general, what is the average volume of fuel left in the bottles?

# LPG Forklift Operator Survey Responses

| SIC | SIC Description | Number of Entries in Phone Database | Number of Class 4/5 Forklifts (propane) | Forklift Size | Method of Fuel Acquisition | Fuel Usage | Units | Week Day | Units | Weekend | Units | Seasonality? | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2448 | Wood Pallets and Skids | 19 | 3 | two 4,000 lb; one 5,000 lb | Bobtail truck fills on-site tank | NA (truck deliveries every 3 weeks) | | 30 | hr/wk | 0 | hrs | N | |
| | | | 2 | one 5,000 lb; one 6,000 lb | Bobtail truck fills on-site tank | 125 | gal/wk (250 gal tank filled every 2 weeks) | 5 to 7 | hrs/d | 0 | hrs | N | |
| | | | 6 | 3,000 to 6,000 lb | Bobtail truck fills on-site tank | NA | | 8 | hrs/d (for 5 lifts) | 0 | hrs | Y | 10% more operation during summer |
| 2653 | Corrugated & Solid Fiber Boxes | 38 | 10 | two 8,000 lb; 8-3,200 lb | Bobtail truck fills on-site tank | NA | | 21 | hr/d | 0 | hrs | N | |
| | | | 5 | three 12,500 lb; two 17,000 lb | Bobtail truck fills on-site tank | 2,000 | gal/mo (2,000 gal tank is filled/topped-off monthly) | 24 | hr/d | 0 | hrs | N | |
| | | | 4 | three 5,000 lb; one 6,000 lb | Cylinder exchange | 30 | cyl/wk | 12 | hr/d | 0 | hrs | N | Variation tied to economy |
| 3499 | Fabricated Metal Products, NEC* | 47 | 2 | NA | Bobtail truck fills on-site tank | 1 | cyl/wk | NA | | NA | | N | |
| 4213 | Trucking Services, except local | 494 | 12 | 2,500 lb to 4,500 lb | Cylinder exchange | NA | | 7.2 | hr/d | 0 | hrs | N | |
| | | | 8 | NA | Cylinder exchange | NA | | 10 | hr/d | 0 | hrs | N | |
| 4225 | General Warehousing | 610 | 1 | 6,000 lb | Cylinder exchange | 1 | 8-gal cyl/wk | 1 | hr/d | 0 | hrs | N | |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 14 | NA | Cylinder exchange | 1,000 to 1,500 | $/mo | 5 | hr/d | See seasonality comment | | Y | Extra 4-hr shift every other weekend during Aug thru Sept. |
| | | | 7 | NA | On-site cylinders | NA | | 6 | hr/d | 5 | hrs/d (Sat only) | N | |
| | | | 4 | 5,000 lb | Cylinder exchange | 350 | $/mo | 4 | hr/d | 0 | hrs | N | |
| 4731 | Arrangement of Transportation of Freight & Cargo | 208 | 15 | NA | Cylinder exchange | 781 | gal/wk | 24 | hr/d | 24 | hr/d | N | |
| | | | 4 | two 3,000 lb; one 5,000 lb; one 8,000 lb | Cylinder exchange | 780 | gal/yr | 1 | hr/d | 0 | hrs | N | |
| | | | 2 | 5,000 lb ea. | Cylinder exchange | 1,400 | lb/mo (for both forklifts) | 12 | hr/d | 0 | hrs | N | |
| 5031 | Lumber, Plywood and Millwork* | 117 | 1 | NA | Cylinder exchange | 1 | cyl/wk | 2 to 3 | hr/d | 0 | hrs | N | Variation tied to new housing market |
| | | | 13 | 5,000 lb ea. | Cylinder exchange | 50 to 60 | cyl/wk | 16 | hr/d | 0 | hrs | Y | Approximatley 50% more usage during summer |
| 5039 | Construction Materials* | 195 | 1 | NA | Cylinder exchange | 66 | gal/wk (two 33-gal cyl) | 3 | hr/d | 0 | hrs | N | |
| 5084 | Industrial Machinery and Equipment | 787 | 1 | NA | On-site tanks | NA | | 2 to 3 | hr/wk | <1 | hr/weekend | Y | Usage rates are for peak season |
| | | | 1 | NA | Cylinder exchange | 1 | cyl/mo | 2 | hr/wk | 0 | hrs | N | |
| 5093 | Scrap and Waste Materials | 200 | 3 | 4,000; 6,000; 8,000 | Bobtail truck fills on-site tank | 10 to 30 | gal/wk | 2 | hr/d | <1 | hr/d | N | |
| | | | 1 | 2,500 lb | On-site cylinder filling | 2 | 30-lb cyl/wk | 4 | hr/d | 0 | hrs | N | Variation tied to scrap metal market |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 2 | NA | Cylinder exchange | 6 | cyl/wk | NA | | 0 | hrs | N | | |
| 5211 | Lumber & Other Bldg. Materials | 656 | 2 | NA | Cylinder exchange | NA | | 3.5 | hr/d | less than weekday | | N | | |
| | | | 1 | NA | Bobtail truck fills on-site tank | 40 | gal/mo (16-gal tank filled 2 to 3 times per month) | NA | | <2 | | hrs/d | Y | Variation is very slight |
| 7359 | Equipment Rental & Leasing, NEC* | 485 | 4 | forklifts are rentals - number and size varies | Rental forklift comes w/filled tank | NA | | 2 | hr/d | 2 | | hr/d (Sat. only) | N | |