Evaluation of KDOT's Vehicle Fleet's CO_2 Emissions and Possible Energy Reductions

By

Eric Nielsen

Submitted to the graduate degree program in Civil Engineering and the Graduate Faculty of the University of Kansas in partial fulfillment of the requirements for the degree of Master of Science.

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Chairperson Dr. Ted Peltier

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Dr. Oswald Chong

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Dr. Dennis Lane

Date Defended: 7 December 2012

The Thesis Committee for Eric Nielsen

certifies that this is the approved version of the following thesis:

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Abstract

Increasing energy demands require more energy extraction from fossil fuels. The energy is extracted through combustion and results in mainly CO_2 emissions as well as other trace emissions. Reducing energy usage can save money and CO_2 emissions. The Kansas Department of Transportation (KDOT) employed the University of Kansas to perform an energy and CO_2 audit in order to identify potential areas for energy savings, as well as create a Microsoft Access database to manage and analyze entries more effectively. Analysis of records provided by KDOT showed an overall decreasing trend in total miles traveled and fuel consumed. It also found that replacing older vehicle models with new models does not show the expected increase in vehicle fleet efficiency across all major vehicle types in the fleet. Using more efficient means of transportation can significantly decrease their fuel demand, namely replacing truck travel with car travel. Additionally, increasing biofuel use in their fleet will decrease their net CO_2 emissions when a full life cycle analysis is considered, although some fuel system problems may arise with higher biofuel blends especially in cold weather.

Acknowledgments

Drs. Ted Peltier, Oswald Chong, and Dennis Lane

Leif Holliday

KDOT staff

KTRAN board

Jeremiah Johnson

Andy Carey

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Introduction/Background

As the global population grows, becomes more technological, and uses more power, energy use and management become a critical issue. Energy management lends itself to the financial realm in potential savings and investment opportunities, legislation from the international scale to local municipalities in reducing regulated emissions, scientific research, and even to individual people and companies in reducing energy costs and emissions. An increased power demand, largely in the form of electricity and liquid fuels, leads to higher prices and more resources. Currently, the resources from which most power is produced are non-renewable fossil fuels such as coal, natural gas, and crude oil that must be extracted from the earth and refined. The non-renewable nature of these resources means there is a limited supply so they must be conserved wherever possible.

Energy conservation through increased efficiencies, lower demand for energy from behavioral changes in users, and increased use of renewable energies is becoming more widespread in many societies due to the recent jump in fossil fuel prices. However, financial cost is not the only price society pays by using fossil fuels. The energy in these fuels is extracted through their combustion which converts the solid or liquid fuel to gases that are emitted through an exhaust system or smoke stack. Typical combustion products are CO_2 and water, although there are small amounts of other compounds emitted depending on what is in the particular fuel and how well it combusts. The general reaction of organic molecules and fuels is shown:

$$(CH_2O)_n + O_2 \rightarrow CO_2 + H_2O$$

The primary environmental concern with combustion processes in vehicles, large equipment, and machinery is their emissions. No matter how well engineered a piece of equipment is, it will always have unfavorable emissions to varying degrees. Such unfavorable emissions include greenhouse gases and other pollutants which can lead to adverse health effects or a decline in environmental quality. Emissions are a concern because of the vast reach of the air quality effects associated with them. Trace emissions are highly variable, can be detrimental, and can cause damage requiring further monetary cost. Some concerns are health related, ranging in severity from respiratory irritation to nausea to possible carcinogenic effects. Still, other effects are environmental and can decrease the quality of ecosystems. For instance, coal often has a high sulfur content which is emitted as SO_2 after combustion. This can lead to acid rain and other adverse health effects even at low concentrations.

For the most part, the health related concerns are well researched, well documented and highly regulated. Acutely toxic products and effects are undesirable, but they are also treatable most of the time via treatment devices like scrubbers or catalytic converters. With treatments like these and frequent monitoring, the concern surrounding trace emissions is dampened so that these serious effects are not as much of an issue from the standpoint of a consumer.

On the other hand, the dominant, large scale species, CO_2, has not been as much of a concern historically due to its low toxicity and apparent benign nature. Recent developments have shifted the concern surrounding CO_2, however. These developments include current and proposed legislation and links to global warming and climate change. In normal and even large scale production, there is no apparent effect from CO_2, but when considering industrial processes on a global scale, the volume of emissions is enough to elicit the impacts of CO_2. Since these effects have been observed, CO_2 has been classified as a pollutant and is therefore able to be regulated by the Environmental Protection Agency (Loris 2009). These regulations focus on net reductions of greenhouse gases.

Regulating greenhouse gases and other emissions is not a new idea. Many environmental summits in the last few decades have attempted to regulate releasing harmful pollutants to the environment. Some of these summits are the Montreal Protocol, the Kyoto Protocol, the Copenhagen Amendments, and the Vienna Amendments. A few results of these conferences include the phasing out of chlorofluorocarbons (CFCs) and attempting to regulate CO_2 emissions, particularly in developing countries (UNFCCC).

CO_2 is a greenhouse gas (GHG) and it is this property that links CO_2 emissions to global warming and climate change. GHGs help insulate the atmosphere by trapping heat energy that would otherwise escape the atmosphere. As the concentration of these gases increases, more and more heat is trapped which can noticeably raise the temperature of the earth's surface. Since environmental systems are so closely related and intertwined, changing one aspect like this can have a significant ripple effect throughout the entire system. For example, as the air warms, the seas also warm and affect dissolved gas concentrations, growth conditions for organisms, and weather patterns. These are just a few examples; the full relationship is much more complex.

The aptly named "greenhouse effect" works just like a greenhouse in that it lets in the sun's radiation but then prevents it from leaving again. Greenhouse gases play the part of the glass in a traditional greenhouse, acting as an insulating barrier between the earth's surface and outer space. In order for this effect to manifest, certain chemical properties must be present to allow a gas to be classified as a GHG; there must be high enough concentrations of GHGs; and there must be an infrared source (generally the earth's surface).

Two common GHGs that get a lot of publicity are methane and CO_2. Methane is a principle constituent of natural gas and has recently been of concern in the world of bovine farming. While methane is a more potent GHG, that is, it has a higher Global Warming Potential (GWP), it is not as large of a concern because of its concentration relative to CO_2; methane's GWP is more than 20x than that ofCO_2, but the concentration of CO_2, ~380 ppm, is about 200x larger than methane, ~1.8 ppm (NCDC ; UNFCCC). CO_2 is much more widely discussed because it is released from anthropogenic sources on such a large scale. Not only is it produced and exhaled by animals, but it is also a direct product of the combustion of fossil fuels. Fossil fuels are the main source of energy for human activities including electrical energy production and transportation. With the current magnitude of these processes already producing noticeable environmental effects, further emissions of such gases are an obvious concern, especially with developing countries increasing their fossil fuel consumption.

Because of the recent legislation passed by the Environmental Protection Agency qualifyingCO_2 as a pollutant (Loris 2009), it is now even more of a priority to cut CO_2 emissions to avoid fines or penalties, although this is not the only reason to reduce emissions. Consuming fewer resources not only reduces combustion and subsequent pollution allowing better air quality, but it also saves money so the motivation to cut energy use is twofold.

With such advantages, many companies are jumping at the chance to cut energy use in both the private and government sectors. One such government agency looking to save pollution and money by reducing energy usage is the Kansas Department of Transportation (KDOT). KDOT employs a large fleet of vehicles and operates buildings throughout the state to achieve the tasks assigned to them. Regular work tasks and travel require energy and financial resources.

Since KDOT is a government agency, fiscal and environmental responsibilities are even more important as a central principle in their public service. In order to maximize their efficiency in these areas, KDOT used KTRAN funding to employ the University of Kansas and Kansas State University to conduct an energy and CO_2audit on their day to day operations. This audit resulted in data that allowed for further analysis and projections for the future. Many of these projections included suggestions for ways to save both money and energy, lowering the financial burden on the taxpayers as well as the CO_2 footprint of KDOT.

The energy audit was proposed as a multiple phase project with Phase I being primarily data acquisition and Phase II analyzing and preparing the data. The project was further broken down into the energy used in buildings versus the energy used in vehicles. Energy use is the easiest way to simultaneously work toward achieving KDOT's goals to reduce both spending and CO_2. This is because energy costs are readily available in the price of fuel or electricity. Such records are simple to maintain and convert from price to units of energy. Because of the strong correlation between CO_2 production and energy use, these records can be used to estimate the CO_2produced from using said energy.

The motivation to reduce spending is obvious, but reducing CO_2 may not be so apparent. While the general public seems to be aware of global climate change and its suspected link to CO_2, they may not be as familiar with the recent legislation surrounding CO_2 and the logical progress these regulations will likely follow. Knowing how much CO_2 they are producing and how it compares to the EPA's likely future regulations is a crucial first step in evaluating subsequent steps for KDOT's activities. This project will provide KDOT with this baseline CO_2 production.

Energy use in buildings was conducted by a different portion of the research group. Their analysis also utilized records provided by KDOT. With vehicles, the energetic cost of actually producing the vehicle and its materials is quite miniscule when compared to operating the vehicle over its entire lifetime. This is not the case with buildings, however. The energy of construction and material production and transportation, known as embodied energy, includes producing the hardware and materials that actually make up the building, as well as operating any machines and equipment during the construction process. This amount of energy cannot be ignored especially when compared to the energy required for operating the building over its lifetime. The building analysis includes the embodied energy for each building in addition to its operational energy demands.

Because this project has separate studies and phases within it, this report is primarily composed of Phase II data for vehicles with some Phase I findings revisited and expounded upon. Phase I for vehicle analysis gathered internal records provided by KDOT for fleet operations from July 2005 through June 2011. These records were combined into a Microsoft Access database to be further developed as part of Phase II. Phase I also conducted preliminary analysis and comparison of purchase and inventory records in order to determine their accuracy. Some of the Phase I findings and figures are included in this report.

In general, fuel consumption and CO_2 are directly related, but there is a bit more to consider when talking about biofuels. Since biofuels come from plant mass and plants use atmospheric CO_2 in their metabolism and life cycle, a full life cycle analysis (LCA) can "reduce" CO_2 emissions without affecting the amount of fuel consumed. It is not a reduction in the sense that less CO_2 is emitted from the vehicle, but in the sense that there will be less CO_2 in the atmosphere from a given vehicle when the carbon-fixing of a plant's life cycle is considered. The "reduction" comes from the apparent atmospheric CO_2 contributed by biofuels and not from using any less fuel. Consequently, there will not be proportional monetary savings by using biofuels. A more in-depth explanation of biofuels and the life cycle analysis will be discussed later in this paper.

Database

Assessing the emissions and subsequent environmental impact requires a framework to look at past records but also allow for future records to be added. As a result of this project, the Kansas Department of Transportation will now have a Microsoft Access database at their disposal for record keeping and data analysis which can serve as an energy accounting tool. This database, titled "Fuel Records Database," has been created and designed by researchers at the University of Kansas through a KTRAN funded project to manage all entries, both past and future, for the KDOT vehicle fleet. It will allow for KDOT's continued analysis of energy usage and allocation without requiring an outside consultant's services. The interface allows for manipulating data as well as adding new entries to existing tables and queries from Microsoft Excel files. Details of how to use the database and its tools can be found in Appendix A, "Fuel Records Database Instructions."

Microsoft Access uses relational databases which utilize rigid relationships between different tables and/or queries that allow for subsequent manipulation, organization, and further relationships. Because of their particular functional strengths, relational databases are the common choice for storing data and implementing basic functionality involving that data.

The database contains all of the records for the vehicle fleet in a number of tables. These records are KDOT's monthly inventory records of vehicle maintenance, mileage, and fuel dating back to July 1, 2005. The fields included in these records contain the internal vehicle ID; vehicle year, make, model, and status; fuel type; monthly fuel amount and price; maintenance charges; and miles traveled to name a few. Records were updated and maintained by KDOT staff in Microsoft Excel files since at least the beginning of fiscal year 2006, July 1, 2005.These Excel files were separated by fiscal year and were electronically delivered to the researchers. The individual files were compiled into the database using Microsoft Access's import wizard. Detailed instructions for importing Microsoft Excel files into Microsoft Access can be found in Appendix A.

Once the files were imported, they were organized into tables. The master table, "Query Date Correction," contains every single entry, regardless of fuel type. Other tables contain every record based on fuel type (diesel, unleaded, and ethanol). The rest of the tables break down the records based on both fuel type and fiscal year. For instance, "All Unleaded" contains every unleaded record and "2008 Unleaded" contains all unleaded records from fiscal year 2009 (June 2008-July 2009).

The tables do not employ any analytical tools beyond column totals because the data are not too meaningful as individual records. Any analysis or calculating is mostly done in the queries. Queries use the same data that is in the tables, but they are able to employ more analytical tools because they can filter and group individual records as well as add calculated fields. The queries themselves are broken down by fuel type and given descriptive titles, similar to the tables. However, the queries only display vehicles whose fuel usage totals at least 100 gallons between all entries from all years. This step cleans up a number of insignificant entries (about 1400 vehicle ID numbers) that would not contribute much in the way of potential fuel and emissions reductions.

The main difference between the tables and queries is that the tables show a row for each record while the queries can group records, in this case by their internal KDOT Vehicle ID. In order for this grouping to be possible, however, some columns of records such as EQUTSTAT (utility status), EQUNSTAT (unit status), and EQCAPA (capacity) could not be included in the queries. The columns that were included in the queries must also grouped by totals for that KDOT Vehicle ID. For clarity, the screenshots below show what has just been described.

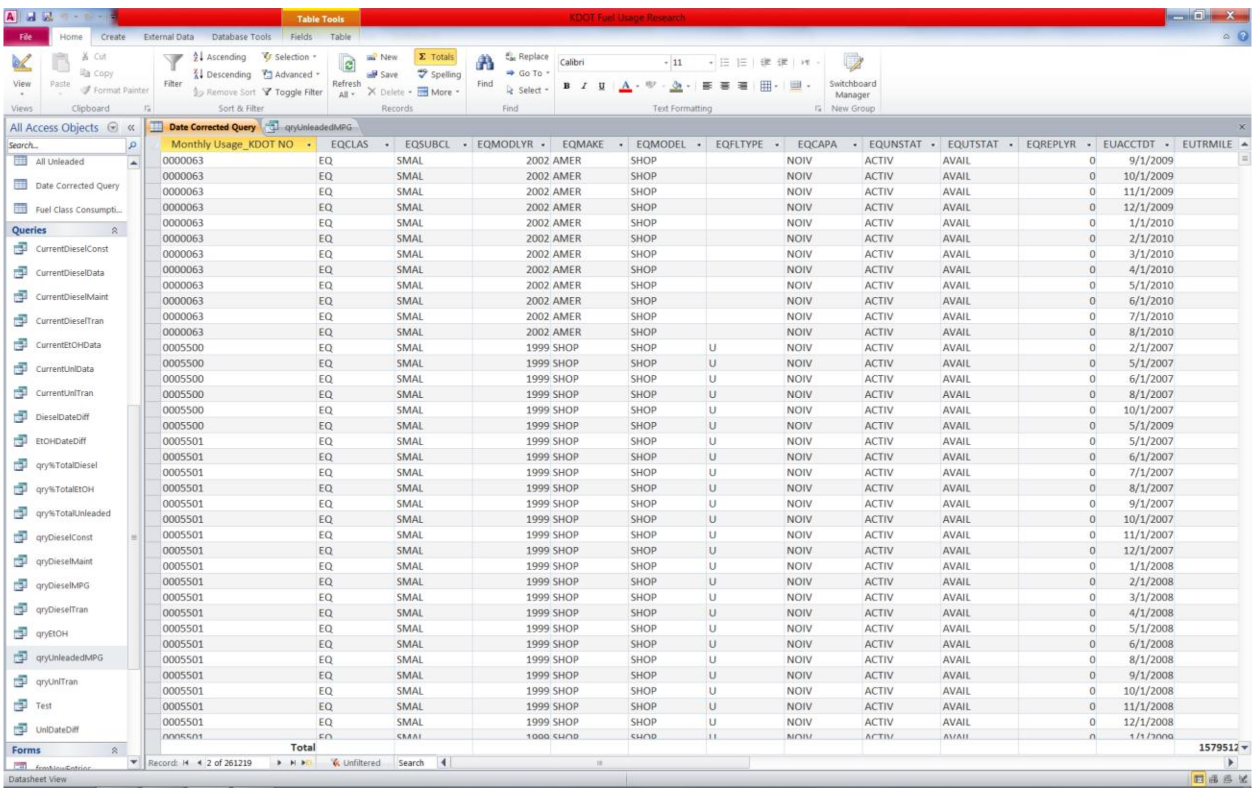
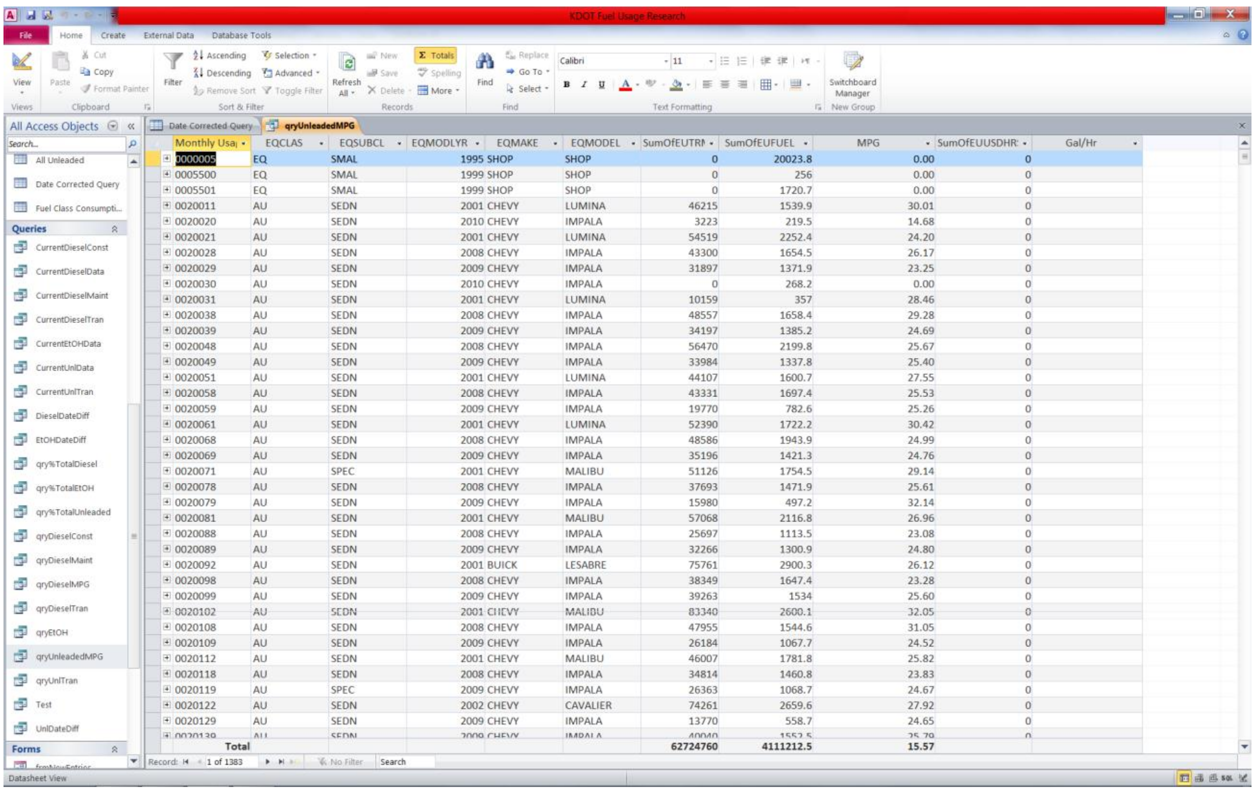


Figure 1- Screenshot from the master table in Fuel Records Database, "Query Date Correction"

The screenshot above shows the master table, “Query Date Correction.” As described before, each row is a separate entry with no grouping of any sort. The screenshot below shows “qryUnleadedMPG” and how each row represents the totaled data grouped by KDOT Vehicle ID. It also shows additional calculated columns including the sums of fuel and miles traveled, as well as MPG. MPG gives an idea of the efficiency of the vehicle and is calculated in the database by dividing the total miles traveled by the total gallons used for a given entry. Compare this view to the previous screenshot from a related table.



Monthly Usa	EQCLAS	EQSUBCL	EQMODLYR	EQMAKE	EQMODEL	SumOfEUTRI	SumOfEUFUEL	MPG	SumOfEUUSDHR	Gal/Hr
0000005	EQ	SMAL	1995	SHOP	SHOP	0	20023.8	0.00	0	
0005500	EQ	SMAL	1999	SHOP	SHOP	0	256	0.00	0	
0005501	EQ	SMAL	1999	SHOP	SHOP	0	1720.7	0.00	0	
0020011	AU	SEDN	2001	CHEVY	LUMINA	46215	1539.9	30.01	0	
0020020	AU	SEDN	2010	CHEVY	IMPALA	3223	219.5	14.68	0	
0020021	AU	SEDN	2001	CHEVY	LUMINA	54519	2252.4	24.20	0	
0020028	AU	SEDN	2008	CHEVY	IMPALA	43300	1654.5	26.17	0	
0020029	AU	SEDN	2009	CHEVY	IMPALA	31897	1371.9	23.25	0	
0020030	AU	SEDN	2010	CHEVY	IMPALA	0	268.2	0.00	0	
0020031	AU	SEDN	2001	CHEVY	LUMINA	10159	357	28.46	0	
0020038	AU	SEDN	2008	CHEVY	IMPALA	48557	1658.4	29.28	0	
0020039	AU	SEDN	2009	CHEVY	IMPALA	34197	1385.2	24.69	0	
0020048	AU	SEDN	2008	CHEVY	IMPALA	56470	2199.8	25.67	0	
0020049	AU	SEDN	2009	CHEVY	IMPALA	33984	1337.8	25.40	0	
0020051	AU	SEDN	2001	CHEVY	LUMINA	44107	1600.7	27.55	0	
0020058	AU	SEDN	2008	CHEVY	IMPALA	43331	1697.4	25.53	0	
0020059	AU	SEDN	2009	CHEVY	IMPALA	19770	782.6	25.26	0	
0020061	AU	SEDN	2001	CHEVY	LUMINA	52390	1722.2	30.42	0	
0020068	AU	SEDN	2008	CHEVY	IMPALA	48586	1943.9	24.99	0	
0020069	AU	SEDN	2009	CHEVY	IMPALA	35196	1421.3	24.76	0	
0020071	AU	SPEC	2001	CHEVY	MALIBU	51126	1754.5	29.14	0	
0020078	AU	SEDN	2008	CHEVY	IMPALA	37693	1471.9	25.61	0	
0020079	AU	SEDN	2009	CHEVY	IMPALA	15980	497.2	32.14	0	
0020081	AU	SEDN	2001	CHEVY	MALIBU	57068	2116.8	26.96	0	
0020088	AU	SEDN	2008	CHEVY	IMPALA	25697	1113.5	23.08	0	
0020089	AU	SEDN	2009	CHEVY	IMPALA	32266	1300.9	24.80	0	
0020092	AU	SEDN	2001	BUICK	LESABRE	75761	2900.3	26.12	0	
0020098	AU	SEDN	2008	CHEVY	IMPALA	38349	1647.4	23.28	0	
0020099	AU	SEDN	2009	CHEVY	IMPALA	39263	1534	25.60	0	
0020102	AU	SEDN	2001	CHEVY	MALIBU	83340	2600.1	32.05	0	
0020108	AU	SEDN	2008	CHEVY	IMPALA	47955	1544.6	31.05	0	
0020109	AU	SEDN	2009	CHEVY	IMPALA	26184	1067.7	24.52	0	
0020112	AU	SEDN	2001	CHEVY	MALIBU	46007	1781.8	25.82	0	
0020118	AU	SEDN	2008	CHEVY	IMPALA	34814	1460.8	23.83	0	
0020119	AU	SPEC	2009	CHEVY	IMPALA	26363	1068.7	24.67	0	
0020122	AU	SEDN	2002	CHEVY	CAVALIER	74261	2659.6	27.92	0	
0020129	AU	SEDN	2009	CHEVY	IMPALA	13770	558.7	24.65	0	
0020139	AU	SEDN	2009	CHEVY	IMPALA	40040	1552.5	25.79	0	
Total						62724760	4111212.5	15.57		

Figure 2- Screenshot from the query, “qryUnleadedMPG” in the Fuel Records Database. This query groups records by the internal vehicle ID with total values for miles traveled, hours used, and fuel consumed for each vehicle ID.

The queries do not limit the user to seeing only totaled records, however. The small plus sign to the left of the KDOT Vehicle ID can be clicked to expand the Subdatasheet. The Subdatasheet is linked to the master table for each fuel type. For example, the screenshot below shows the Subdatasheet for KDOT Vehicle ID 0005500 in the query “qryUnleadedMPG.” The records and columns displayed in the Subdatasheet are not abbreviated, grouped, or edited in any way so the expanded display matches exactly what would be seen in the “All Unleaded” table for a particular KDOT Vehicle ID. This allows users to easily see the detailed entries for a specific vehicle as well as the calculated fields of the query without having to switch back and forth between tables and queries.

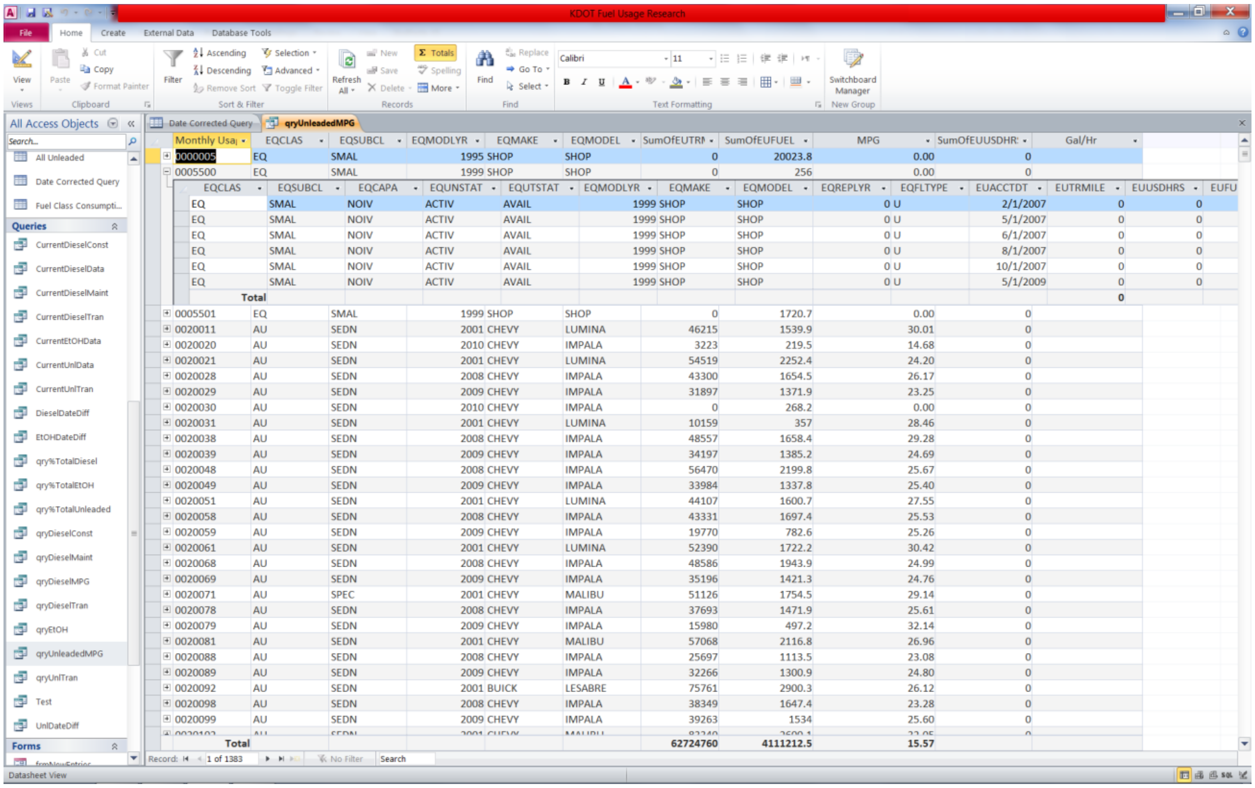


Figure 3- Screenshot from the query, "qryUnleadedMPG" in the Fuel Records Database with the Subdatasheet expanded to show all individual records from the master table for a particular vehicle ID, in this case 0005500.

Just as the different tables break down the records on different levels, so do the queries. Each fuel type has a query to analyze data from all the years on record as well as a query that can be set to include records from a specific time period. Queries with "Current" in the title are the queries with customizable time periods. Specific directions on how to set the time period can be found in Appendix A.

The calculated fields are what allow for meaningful analysis. These columns are MPG, GPH, and percent of usage. Miles per gallon is the most familiar tool for evaluating a vehicle's efficiency. Efficiency, η, can be represented by the amount of work output divided by the work or energy input ($\eta = \frac{work_{out}}{work_{in}}$). MPG shows how much work is done or output (how far the vehicle travels) with a certain volume of fuel (a certain amount of energy).This field is calculated for all vehicles and all three fuel types.

MPG has limitations for its viability as an appropriate assessment of efficiency for some vehicles in KDOT's inventory. Vehicles and equipment which are often stationary during operation will appear to have a much lower efficiency based on MPG than they may actually have in reality. Another measurement, gallons per hour, was used to remedy this problem. Gallons per hour are calculated by dividing the total fuel by the hours the vehicle was used. This measurement is useful by giving an idea of how much work is done or output by a certain volume of fuel.

Both MPG and GPH are calculated for every entry, although there may not be a value available for every entry due to the records themselves. For example, a record that has no data for hours used cannot produce a value for gallons per hour. Examples of equipment that are more appropriately evaluated using GPH include generators, trailers, tractors, and dump trucks. Even though some of this equipment can travel many miles, there is often significant operating time while stationary due to hydraulic systems in dump trucks or local work such as backhoes and, therefore, skew the apparent efficiency should it only be reported in MPG.

Once these values exist in the calculated fields, the data can then be analyzed further by way of graphs or charts. The reports have these tools available and are linked to the queries, just as the queries are linked to the tables. This link means that any changes in a table or query will automatically be reflected in the reports and all of the reports' calculated fields or charts.

Database findings

The Microsoft Access database created for KDOT in this project has many tools that allow for analysis of records in just a few steps. Records can be analyzed using multiple queries or reports, but the reports provide a much more complete analysis of entries and make any trends easy to see via the generated graphs. Some additional analyses were performed outside of these simple averages and sums from the database tools. These findings shall be explained and reported here in conjunction with the database findings.

Initial work with the records received from KDOT show that an overwhelming percentage of the entries and use are for diesel vehicles or equipment. Diesel equipment accounts for 61% of the entries, while unleaded entries make up 25%, and ethanol entries make up 1%. The remaining 13% either do not have a fuel type specified or are a different, non-standard fuel type still, noted as A, N, P, or R. The following charts show visually the breakdown of standard fuel type.

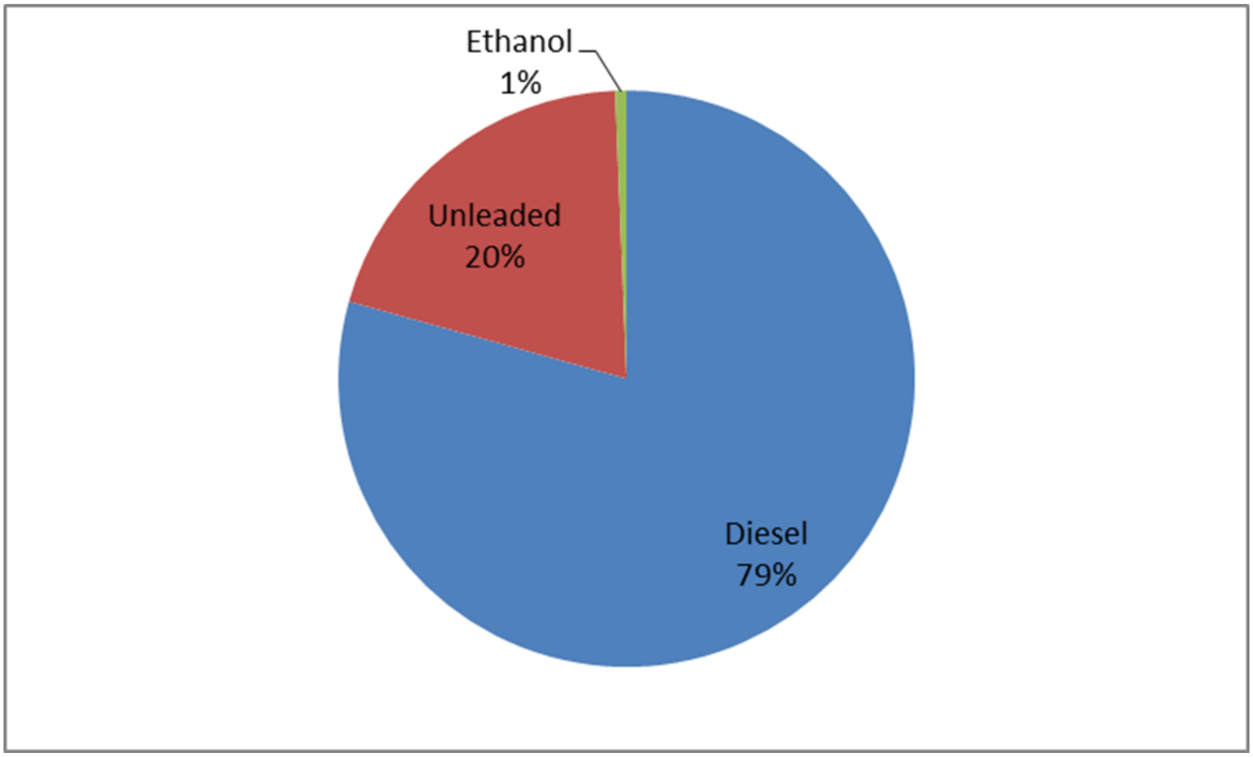


Figure 4-Relative fuel consumption by fuel type

All of the records for ethanol vehicles may not reflect actual ethanol use, but, rather the fact that the vehicle is identified as an E85 flex fuel vehicle (FFV). That is, a record may show ten gallons of fuel for an ethanol vehicle even though the added fuel is actually unleaded fuel. This entry would remain in the ethanol records since it belongs to an E85 FFV. Even so, the amount of fuel in these vehicles, about 131,000 gallons, is still not significant enough to offer savings on a meaningful scale when compared to the 4 million and 16 million gallons of unleaded and diesel, respectively. Biodiesel was not clearly distinguished from diesel in the records received from KDOT, nor was it stated how the biodiesel was purchased (as B100, B20, etc.) so diesel and biodiesel records were treated as the same fuel.

The totals of miles traveled, hours used, and fuel consumed are calculated and shown at the bottom of the column in each table. Looking at the total quantity of each type of fuel used shows similar relationships to the entries previously discussed, with diesel representing about 79% of the total 20 million gallons of fuel in the database. These relationships suggest that diesel has the highest potential for reduction and savings. Unleaded also merits analysis for potential savings, but ethanol does not show much promise for savings due to its relatively small use in KDOT's fleet. Slightly more in-depth analysis of these preliminary numbers shows an agreement between inventory and purchase records. An initial discrepancy in the unleaded records is suspected to be due to interdepartmental use with the Kansas Highway Patrol. This is supported by records from fiscal year 2011 (the only records of this type received) that show KDOT vehicles used only about 60.5% of the total fuel pumped at their filling stations.

An analysis of the records within each fuel type yields parallel results with respect to vehicle class. Trucks are the largest users in both diesel and unleaded fuels with 73.7% and 74.2% of the total fuel usage, respectively. The following tables show more detail for additional vehicle classes within each fuel type.

Table 1- Fraction of fuel use by equipment class. Tabular form of Figure 4.

Class	Description	Diesel Fuel	Fraction of Total Diesel Fuel
TK	Truck	10188628	0.73766573
TC	Tractor	1203558	0.08713867
LR	Loader	875530	0.063389151
MG	Motor grader	596635	0.043196905
DT	Asphalt distributor	244513	0.017702959

Class	Description	Gasoline	Fraction of Gasoline
TK	Truck	2700659	0.741820065
AU	Auto	494155	0.135735054
VN	Van	324311	0.089082112
SW	Sweeper	22072	0.006062762
EQ	Equipment	20506	0.005632611

These numbers reflect the expected breakdown when considering a vehicle fleet such as KDOT's since trucks are generally the appropriate vehicle of choice for the department's workloads. If these numbers are broken down into yet another subset and analyzed based on end-use work type which can be seen in Table 2, then the results are not quite as intuitive, especially with diesel. Surprisingly, transportation is responsible for the smallest amount of fuel consumption among diesel vehicles in the end-uses categorized in this study. The types of work were classified by logical uses based on vehicle entry details such as dump trucks versus light duty pickups or sedans.

After all of this preliminary analysis of the records, a simple CO_2 estimation based on EPA conversion factors was used to assess the magnitude of emissions of KDOT's vehicle fleet. Diesel fuel was estimated to produce 22.4 pounds of CO_2 per gallon and unleaded was estimated at 19.6 pounds of CO_2 per gallon (EPA 2011). The chart below shows the breakdown of relative

CO_2 production by fuel type. If this figure is compared to Figure 4, the different amount of CO_2 produced per gallon of fuel can be seen in the relative percentages, i. e. diesel is 79% of fuel used but responsible for 81% of the CO_2 produced. This is due to the different compositions of the fuels, namely the differences in the amount of carbon per gallon; if there is more carbon in the fuel initially, then there will be more carbon after combustion as well (CO_2). The carbon content per gallon of diesel is ~87% by mass while unleaded is ~82% by mass, accounting for the slightly higher diesel contributions (CRC 2011).

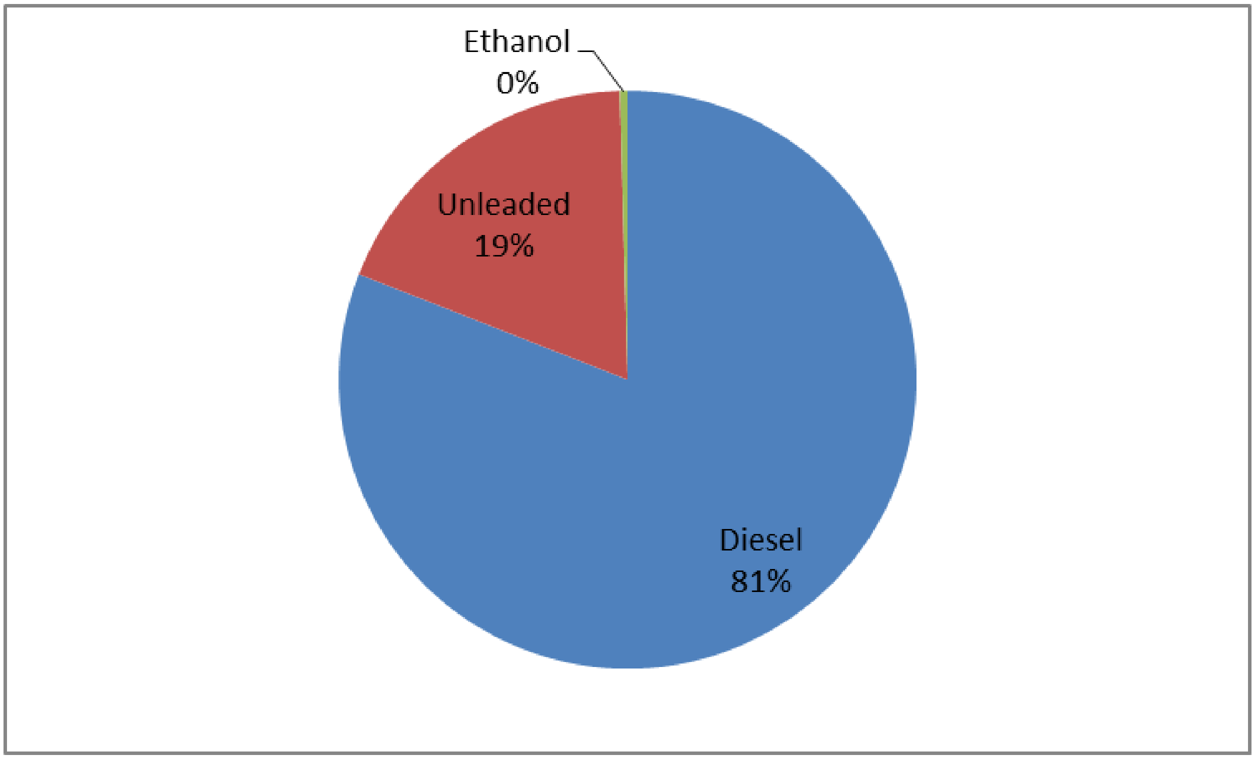


Figure 5- Break down of CO_2 produced by each fuel type

Since there are different vehicle classes and types for diesel versus unleaded, the two fuel types will be discussed separately. Diesel vehicles were broken down into three main categories for end-uses: transportation, construction, and maintenance. Vehicles were assigned to end-use categories based on their vehicle subclass (EQSUBCL in the database). Their inclusion or exclusion in a category was based on the researchers' evaluation of whether or not they could reasonably complete the work task. It must also be considered that different classes of vehicles can be employed for more than one end-use. For instance, dump trucks were included in both construction and maintenance in this study. This overlap allows for fuel use percentages to total more than 100% in Table 2.

It was found upon initial evaluation that dump trucks themselves are a large consumer of the department's fuel inventory. Over the six years of data compiled in the database, dump trucks accounted for 55% of the total diesel fuel. Such a large portion prompted a separate analysis of dump truck records as a fourth category under diesel usage, along with construction, maintenance, and transportation. The following table breaks down the fuel consumption based on end-use and the combined six-year totals. The numbers in parentheses represent the percentage of diesel used for construction and maintenance if dump trucks are not included in the calculation. GPH are not reported for dump trucks because of a large number of suspicious and unrealistic records skewing the average dramatically (>500 GPH even up to ~6500 GPH). GPH is not shown for transportation because there are no records for hours used for those vehicles.

Table 2- Break down of fuel consumption by end-use. Numbers in parentheses show calculations neglecting dump truck consumption.

	Diesel		
Use	% of Total	MPG	GPH
Construction	74% (19%)	2.73	16.1
Maintenance	68% (13%)	3.36	20.9
Transportation	17%	14.1	-
Dump trucks	55%	5.63	-
	Unleaded		
Transportation	97%	16.7	-
	Ethanol		
Transportation	100%	24	-

The only vehicles assigned to transportation in the diesel category were of EQCLAS=TK (trucks). The subclasses within this class that were deemed suitable for transportation analysis were full size to light pickup trucks or SUV's capable of easily transporting passengers more reasonably than hauling equipment.

The vehicles assigned to construction were heavy duty trucks, dump trucks, dozers, rollers, loaders, cranes, tractors, and similar equipment. Maintenance vehicles have extensive overlap within trucks, tractors, and dozers when compared to construction equipment, but that is where the similarities stop. The rest of the maintenance vehicles are mowers, compressors, chippers, sweepers, and tillers.

It was found that after an upward trend for the first three years, the overall CO_2 emissions, represented by the line of best fit, had decreased for both diesel and unleaded. The decreasing trend is likely attributable to efforts by KDOT staff to drive more economically. With diesel, however, much of the consumed fuel is in vehicles performing jobs other than solely transportation. Driving economically can only affect the trend to a certain degree before the sheer volume of non-transport work influences the trend. Graphs illustrating the decrease can be seen below in Figures 6, 7, and 8.

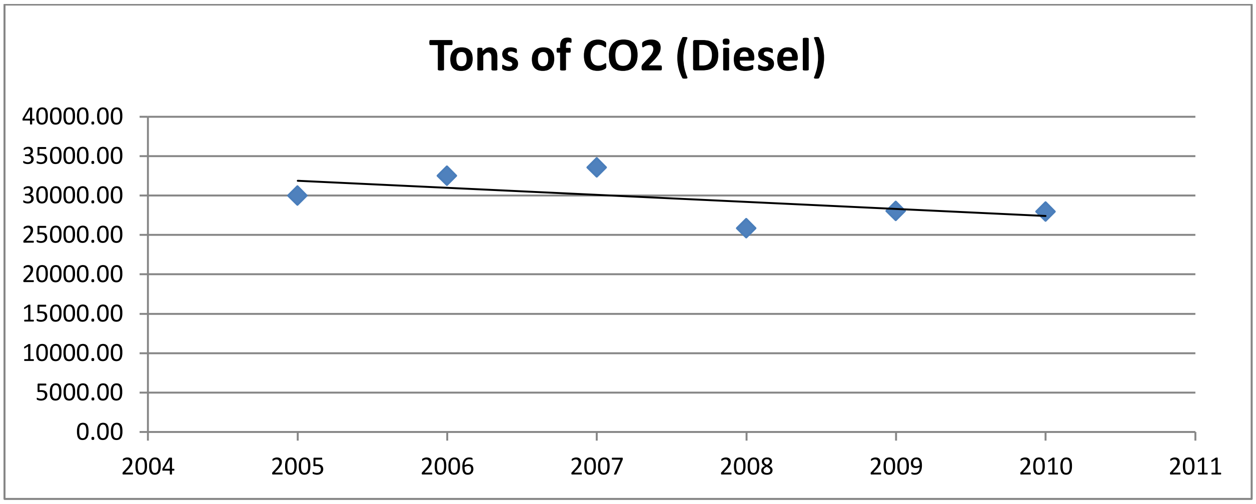


Figure 6- Tons of CO_2 produced by diesel fuel consumption in each fiscal year.

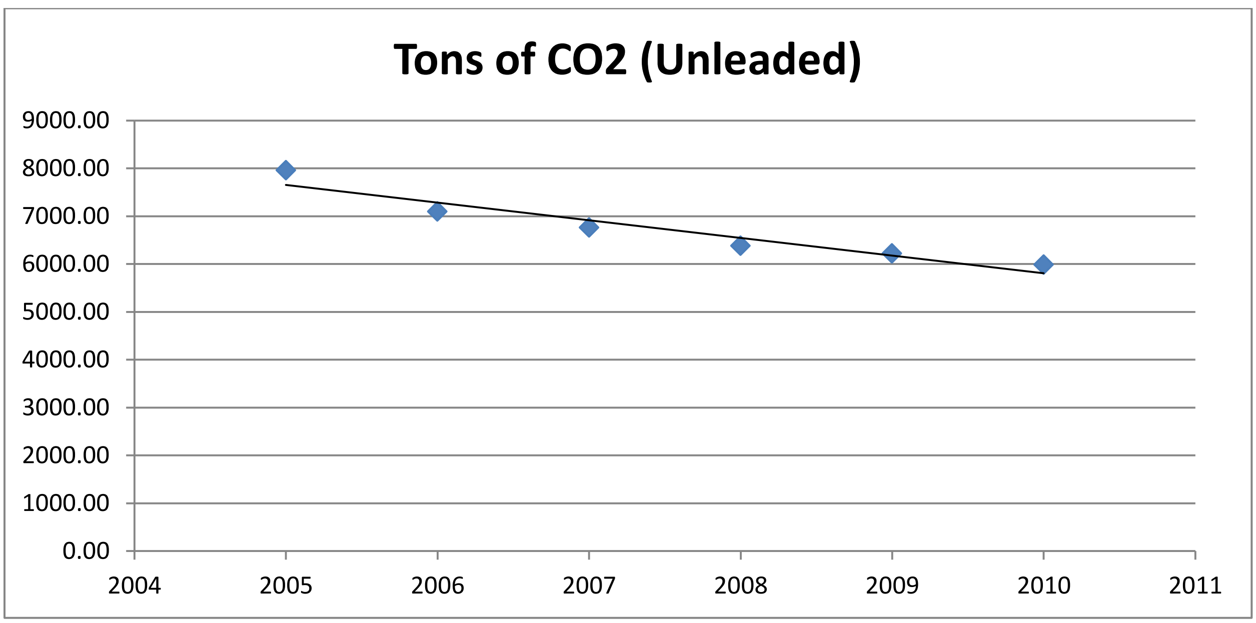


Figure 7- Tons of CO_2 produced by unleaded fuel consumption in each fiscal year.

Because virtually all unleaded fuel is used for transportation, the unleaded trend is much more uniformly linear and driving more economically will be the only influence in affecting the trend, barring any large changes in amount of travel.

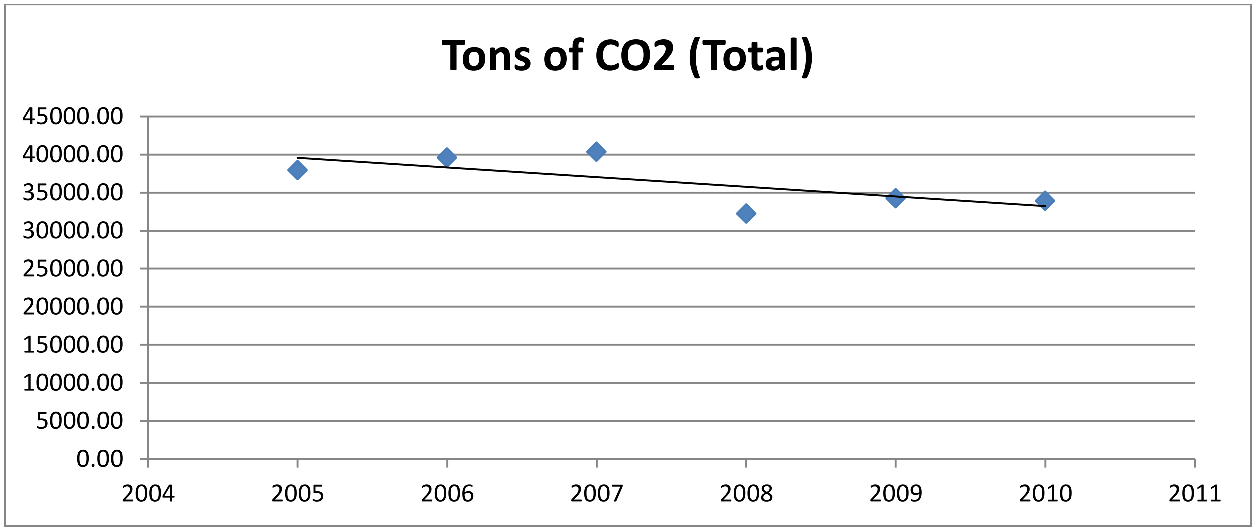


Figure 8- Tons of CO_2 *produced by total fuel consumption for each fiscal year.*

Additional analyses of the records were performed to find where the CO_2 reductions were likely coming from. The most obvious contributor to reducing these emissions was total fuel consumed. Plotting fuel usage by fiscal year, just as was done for CO_2, showed very similar results and can be seen in the following graphs, Figures 9, 10, and 11.

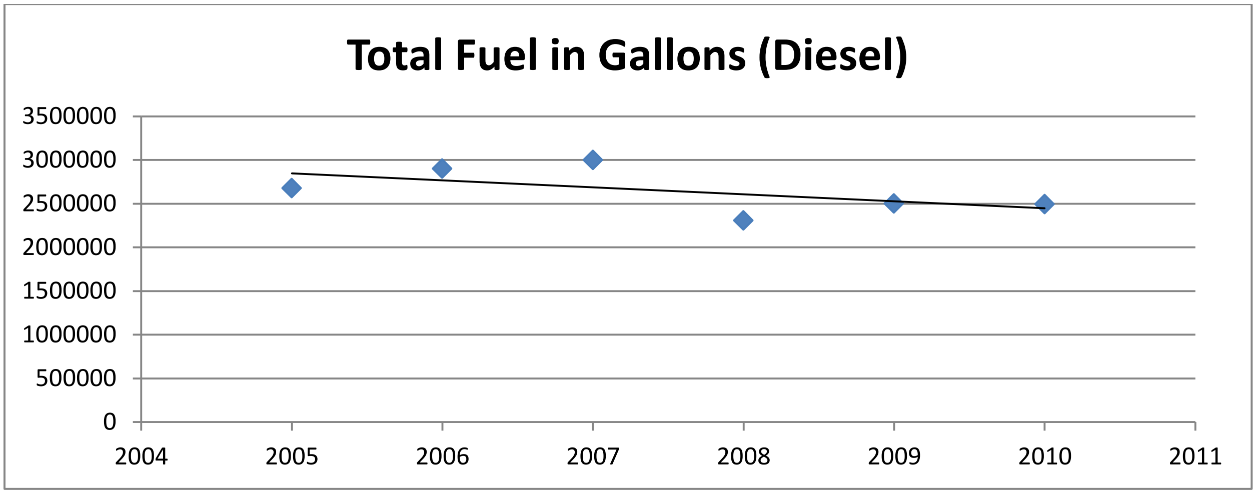


Figure 9- Total gallons of diesel fuel consumed in each fiscal year.

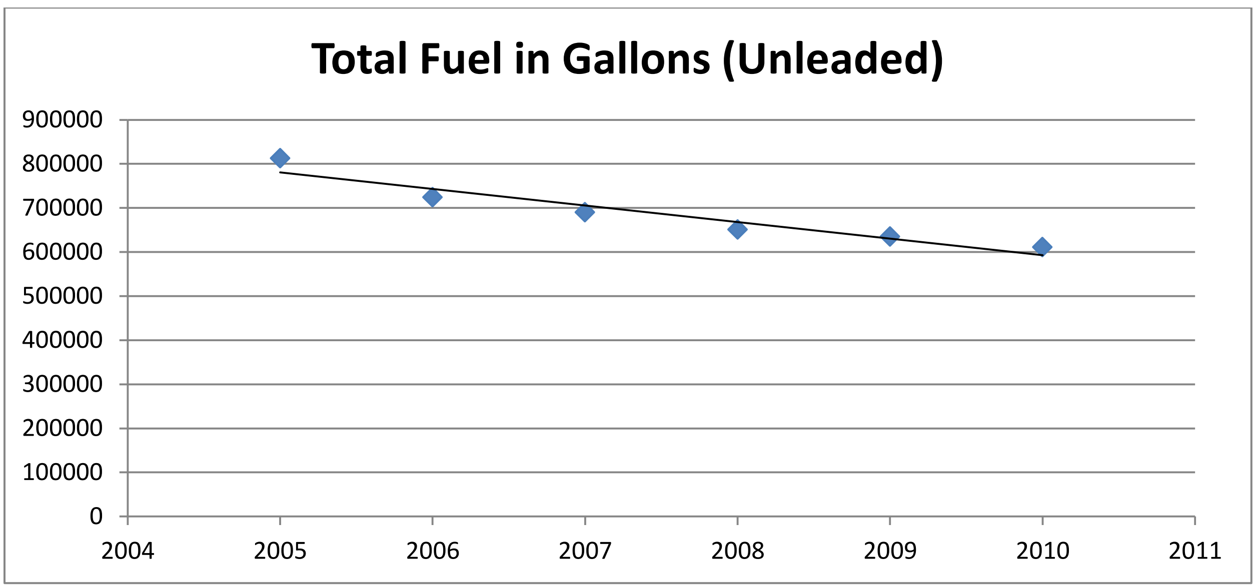


Figure 10- Total gallons of unleaded fuel consumed in each fiscal year.

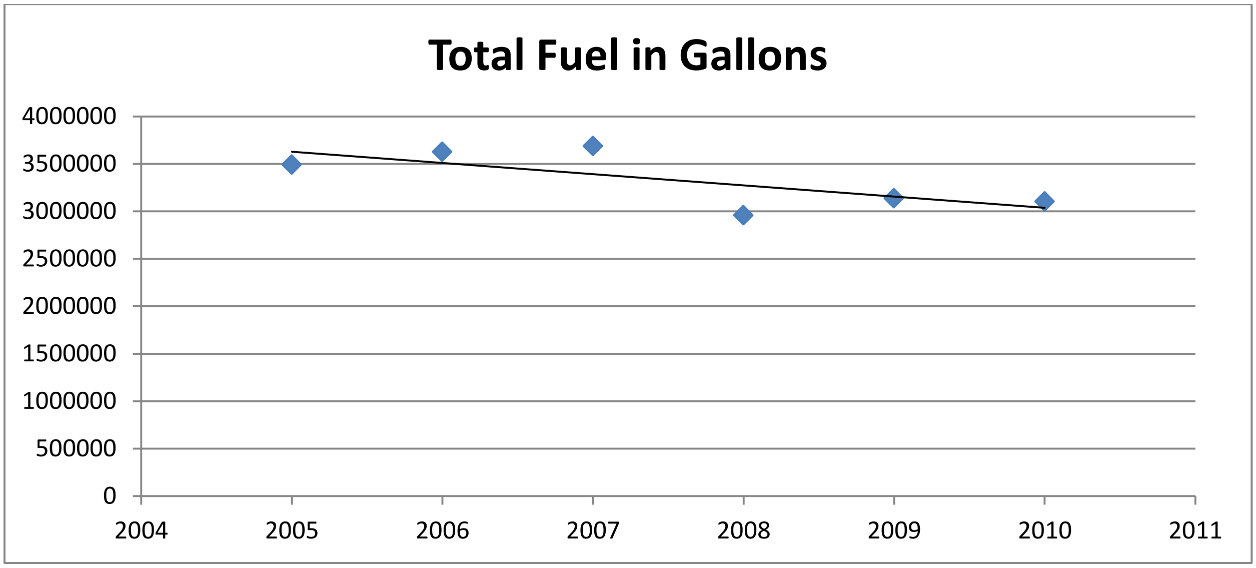


Figure 11- Total gallons of fuel consumed in each fiscal year.

Similarly, the miles traveled each fiscal year were plotted and yielded results very comparable to those seen in the other two types of figures. The close agreement between the fuel consumed and miles traveled plots also shows that there is no significant variation in the MPG of either fuel over this time period.

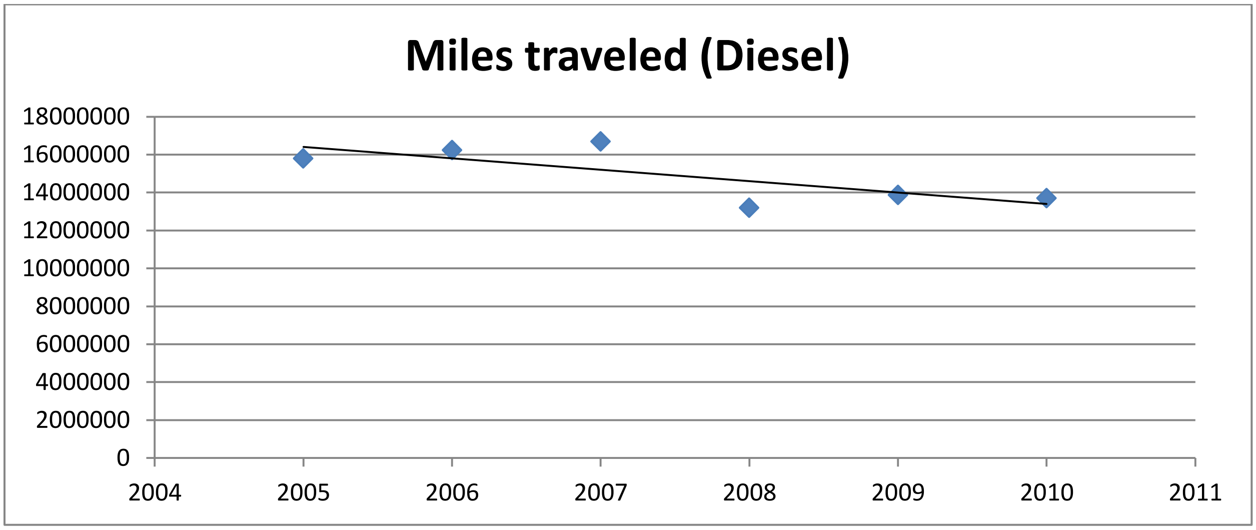


Figure 12- Total miles traveled in diesel vehicles for each fiscal year.

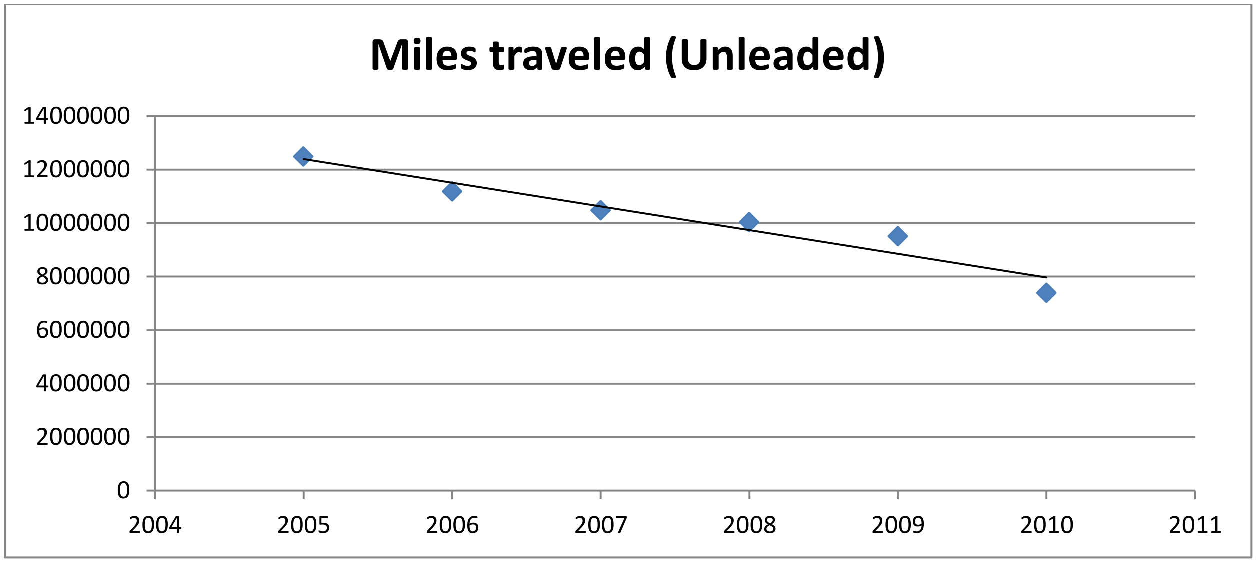


Figure 13- Total miles traveled in unleaded vehicles for each fiscal year.

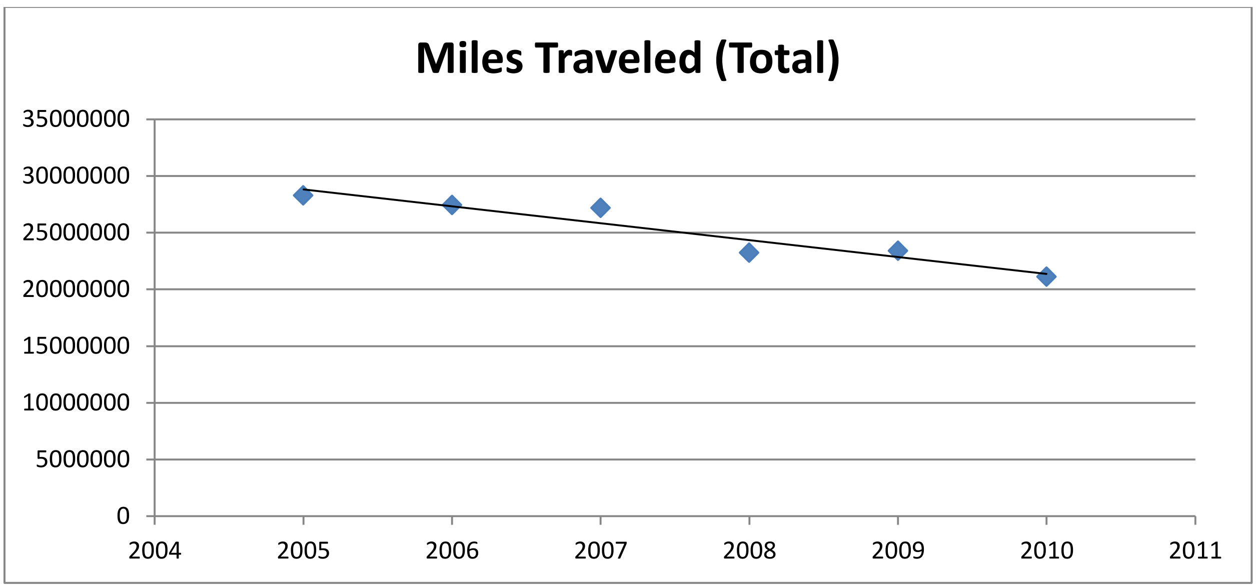


Figure 14- Total miles traveled in all vehicles for each fiscal year.

In light of the mandated increase in fuel efficiency of new vehicle models and more stringent regulations, newer vehicles have improved their performance. Looking at the numbers in the database with respect to a trend of model year was expected to show a similar increase in efficiency in more recent model years. Actual analysis of the records did not show a significant increase in any case, and, in fact, showed a negative trend in all cases presented here. Figures 15, 16, 17, and 18show the average MPG for vehicles by model year.

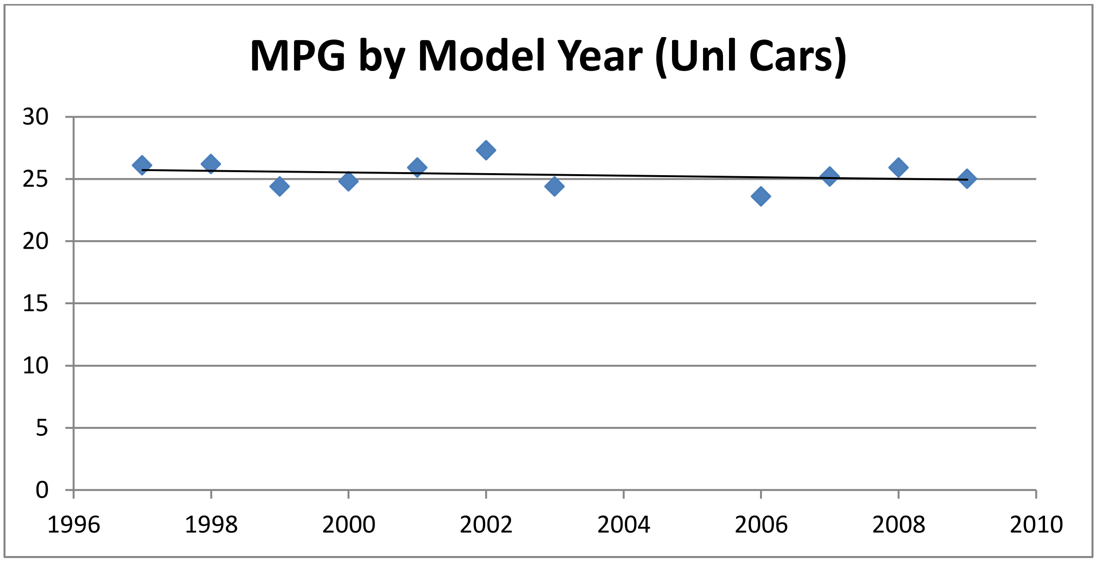


Figure 15- MPG efficiency for each model year for unleaded cars. The point for 1997 represents all cars model year 1997 and older.

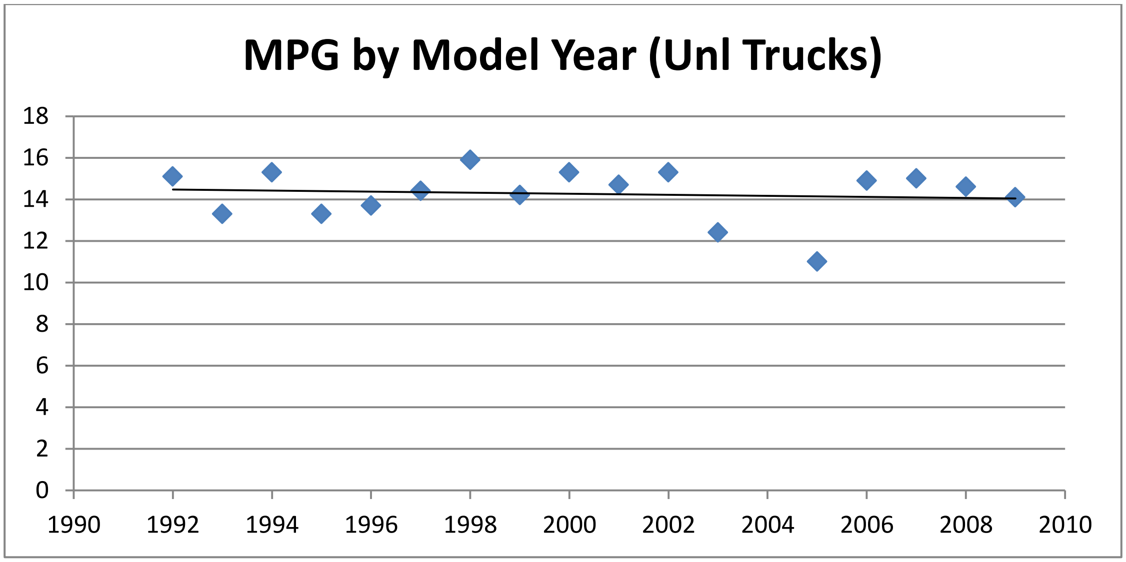


Figure 16- MPG efficiency for each model year for unleaded trucks. The point for 1992 represents all unleaded trucks for model year 1992 and older.

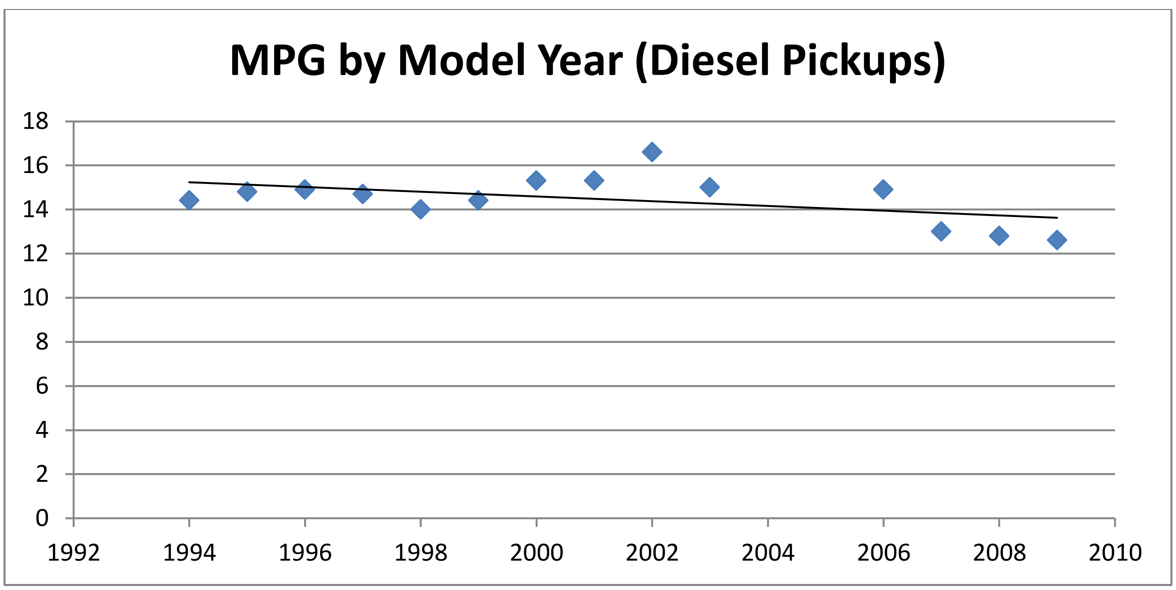


Figure 17- MPG efficiency for each model year for diesel pickups. The point for 1994 represents all diesel pickups for model year 1994 and older.

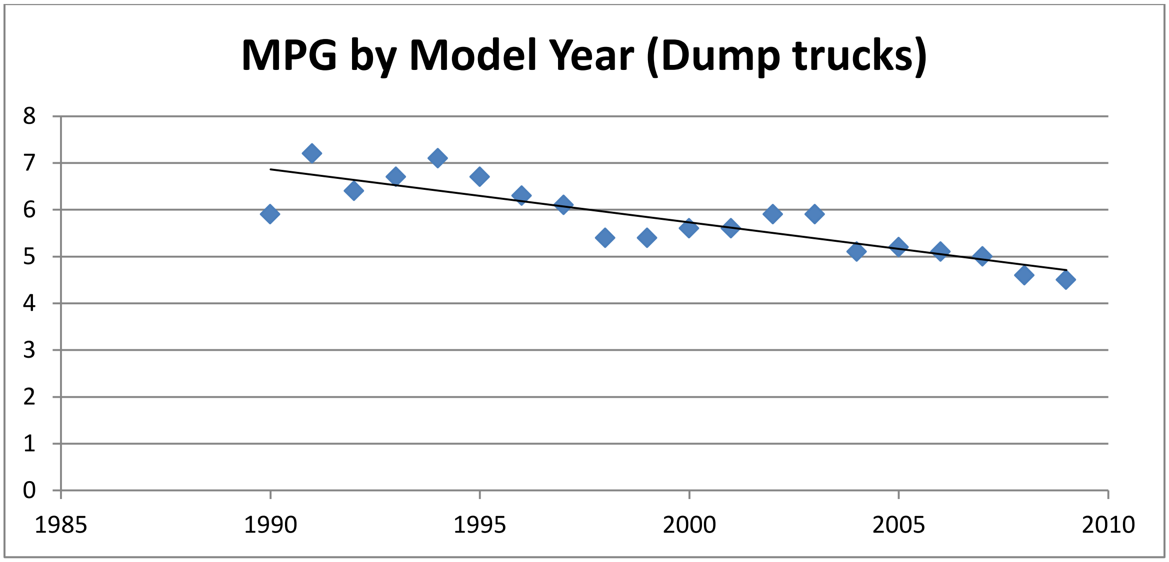


Figure 18- MPG efficiency for each model year for dump trucks. The point for 1990 represents all dump trucks for model year 1990 and older.

The line of best fit for these data shows a negative slope in all cases, indicating a negative trend in MPG efficiency with more recent model years. Such a negative trend would suggest that replacing older vehicles with newer ones will negatively affect the overall MPG efficiency of KDOT's fleet. The most extreme example of a negative trend is in dump trucks. Further investigation showed that the decrease in efficiency is likely due to an increase in size or power of the same models in subsequent years. For example, the 210 horsepower 1999 Sterling LT7500 is smaller and less powerful than the 250 horsepower 2005 Sterling LT7500 despite being the same model (www.commercialtrucktrader.com). More power requires more energy and thus more fuel, causing a decrease in MPG efficiency. This means that despite KDOT replacing old vehicles with identical models from newer years, the MPG efficiency of the fleet will ultimately decrease.

If these same numbers for efficiency and pollution are shown in terms of money rather than miles, the results are more easily relatable. It must be noted, however, that the following calculations are based on a consistent price of $3.35/gallon of unleaded and $3.60/gallon of diesel. These were conservative values compared to the national prices at the time of the report, and there are no indications that there will be any large changes in the near future.

The high degree of fluctuation in the price of fuel will allow for related changes in these numbers, but the general trend is expected to stay the same, save unforeseen breakthroughs or drastic changes in production, demand, taxes, or mandates for a certain fuel. The general trend expected to continue is that diesel will cost slightly more per gallon than unleaded due to higher taxes, distribution costs, and extra refining steps, particularly sulfur removal(EIA 2012). This well-known trend is historically supported since the June 2006requirement of ultra-low sulfur diesel (ULSD) and can be seen in Figure 19 with data provided by the U. S. Energy Information Administration (EPA 2006; EIA 2012).

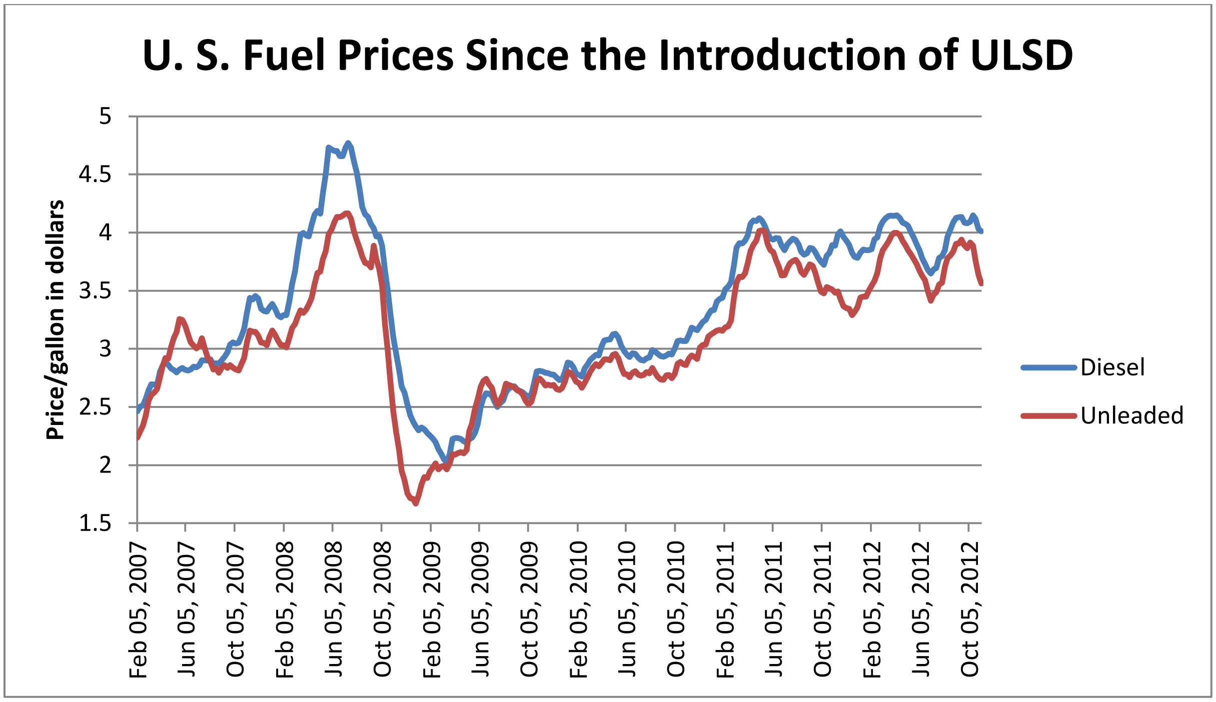


Figure 19- Weekly data of national average prices per gallon of diesel and unleaded fuels since the introduction of ultra-low sulfur diesel (ULSD).

The financial analysis can be seen in the tables below. These calculations show that diesel is less fiscally efficient in terms of both mileage and CO_2 production, even though it contains more energy per gallon.

Table 3- Break down of efficiency of fuel and vehicle types in miles per dollar (@$3.35/gallon of unleaded and @$3.60/gallon of diesel)

Transportation Vehicles	Miles/Dollar
Truck (D)	3.97
Truck (U)	4.33
Car (U)	7.55

Table 4- Break down of CO_2 production in terms of pounds of CO_2 per dollar (@$3.35/gallon of unleaded and @$3.60/gallon of diesel)

Fuel Type	lbs CO2/dollar
Diesel	5.56
Unleaded	5.46

Similar calculations using energy units of megajoules (MJ) as the common ground for comparison were performed to show the same analysis in terms of energy. The results of these calculations are in the following table. To put things into perspective, it takes about 0.08 MJ, or the energy in about three mL of gasoline, to boil one cup of water. The ideal fuel would have high energy (MJ) per gallon, high energy per dollar, high energy per lbCO_2, and low energy expended per mile. The value shown in parentheses is the result based on unleaded car efficiency, while the other numbers are for transportation trucks. The table shows that unleaded fuel is more favorable than diesel in both categories related to performance, energy per lbCO_2 and energy per mile. Unleaded yields slightly less energy per dollar than diesel, but the higher process efficiency makes up for it. Also, remember that price is highly variable so the per dollar relationship is not a constant value but likely a constant relationship between fuel types. All of the other numbers use constant values based on physical and chemical properties and are therefore constant. Energy densities were adapted from (Berkeley_Labs).

Table 5- Break down of fuel performance in terms of energy (MJ, megajoules) per gallon, dollar, pounds of CO_2, and miles traveled. Fuel cost assumed to be $3.35/gallon of unleaded and $3.60/gallon of diesel. The number in parentheses represents the MJ/mile based on unleaded car efficiency of 25.3 MPG. The number outside parentheses represents MJ/mile based on unleaded truck efficiency of 14.5 MPG.

Diesel	Unleaded
149.1 MJ/gallon	132.1 MJ/gallon
41.42 MJ/dollar	40.65 MJ/dollar
6.656 MJ/lb CO2	6.740 MJ/lb CO2
10.43 MJ/mile	9.11 (5.22) MJ/mile

All of these findings and analyses are very telling about current use but have not yet been utilized to shape future numbers. Obviously diesel has the greatest potential for savings and reduction, considering that it is the overwhelming majority of fuel usage. A few different options are available for these savings. Some of these options could be implemented as a system while others would depend on individual drivers and operators.

Reductions could be achieved by an increase in efficiency of all the vehicles in KDOT's fleet which could most easily be influenced by their operators. Since the operators are highly variable and not easily controlled, however, it is most likely not a reasonable solution. An example of a more systematic and, consequently, reliable measure would be substituting some generic travel in pickups with travel in cars. The calculations explained here show how substituting a small percentage can have dramatic effects on fuel consumption and CO_2 emissions.

For a 20% conversion of unleaded pickup truck miles to unleaded cars, the total pickup truck miles should be multiplied by 0.2 to give about 8 million miles. Divide the number of miles by the MPG efficiency of both unleaded trucks (14.5) and cars (25.3) to get the total number of gallons of fuel required to travel the 8 million miles. Subtracting these two values (556,705 (trucks) – 319,060 (cars)) gives the number of gallons that would be saved. To get the subsequent reduction in CO_2 emissions, multiply the gallons for both cars and trucks by the EPA estimated CO_2 conversions and find the difference again. In this case, the CO_2 savings would be about 2174 tons. Analogous calculations for monetary savings yield about $800,000 saved @ $3.35/gallon of unleaded fuel. These calculations were performed from 0-30% at 5% intervals for unleaded trucks to unleaded cars, diesel trucks to unleaded cars*, and diesel trucks to unleaded trucks*.Results of these calculations can be seen in Figures 20-28.

The asterisk in the diesel calculations points out the differences between unleaded and diesel fuels (heating values, densities, CO_2 produced). Diesel has more energy per volume than unleaded fuel (CRC Handbook). Since efficiency in vehicles is measured per volume (miles/gallon), it means that diesel has more energy per gallon which would mean two identical vehicles running different fuel types should produce more MPG using diesel than unleaded with all other things being equal. The asterisk denotes the fact that the figure for gallons saved was not used directly in subsequent calculations of price or CO_2 because a gallon of diesel and a gallon of unleaded are not the same in terms of volume, energy, price, or CO_2 produced. Instead, the total diesel or total unleaded that would be required based on the MPG averages was used, as described in the sample calculations above.

The figure reported for gallons saved is the difference of these two total fuel required numbers, although this number still does not reflect a highly accurate number because of the "apples to oranges" comparison of the different fuels. The $CO_2$and total cost savings were calculated in the same manner as the gallons of fuel, but the accuracy of these calculations is not in question due to the directly comparable units in each calculation (lbs CO_2 and price) despite different fuel types. (Unleaded fuel is estimated at 19.6lbs/gallon and diesel fuel is estimated at 22.4lbs/gallon, so the difference in materials is accounted for in these numbers (EPA 2011).)

These calculations were repeated in 5% increments from 0-30% and plotted to show potential savings at different mileage conversions. A third scenario was also plotted that graphically analyzes the same mileage conversions but instead of using unleaded cars as the proposed solution, it uses unleaded trucks in place of diesel. This may be a good compromise for monetary and CO_2 savings since the efficiency is slightly higher in unleaded trucks when compared to diesel pickups and the relative CO_2 emissions are lower with unleaded fuel (as previously discussed), but it still allows access to trucks for tasks that may be too heavy duty for cars. The graphs showing the results for fuel savings can be seen below.

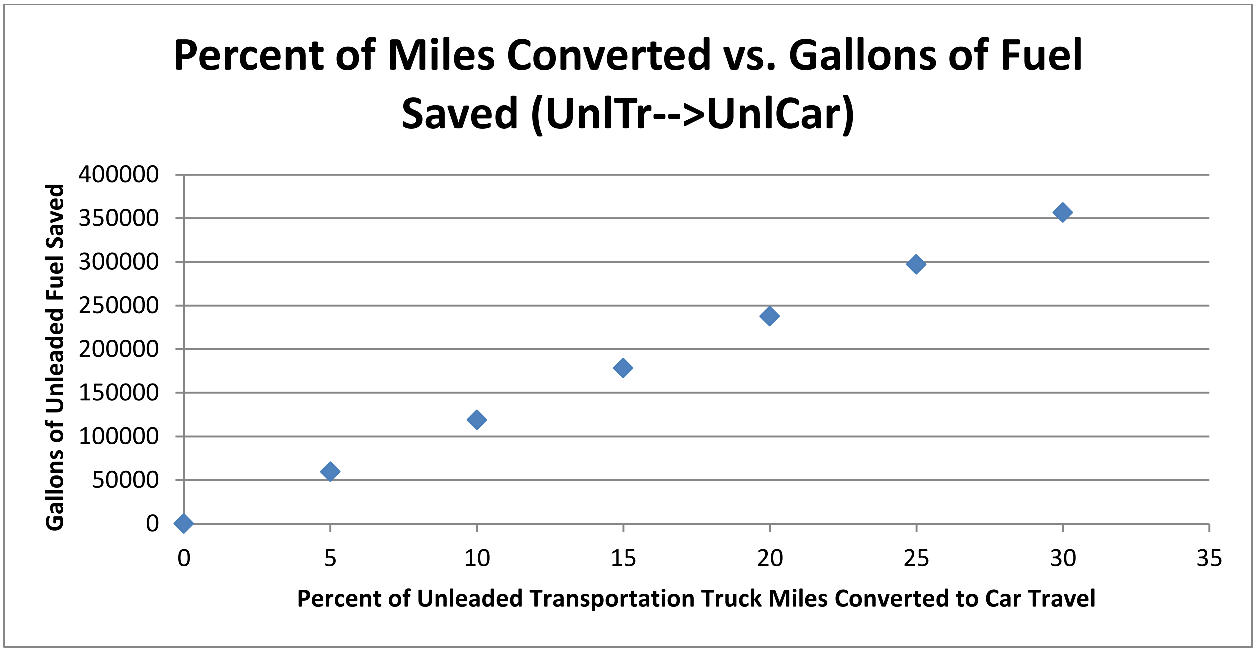


Figure 20- Graph representing the gallons of unleaded fuel that would have been saved based on the six years of data provided by converting unleaded truck travel to unleaded car travel from a 0% conversion to a 30% conversion.

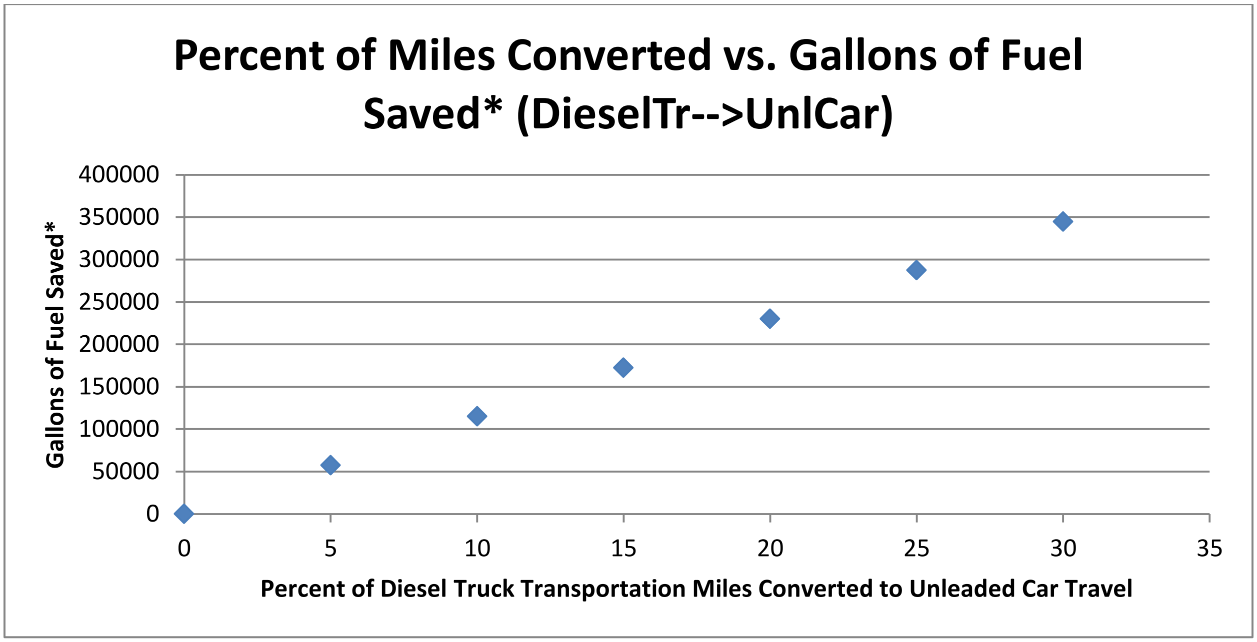


Figure 21- Graph representing the gallons of fuel that would have been saved based on the six years of data provided by converting diesel truck travel to unleaded car travel from a 0% conversion to a 30% conversion. Asterisk denotes different energy contents of unleaded and diesel fuel.

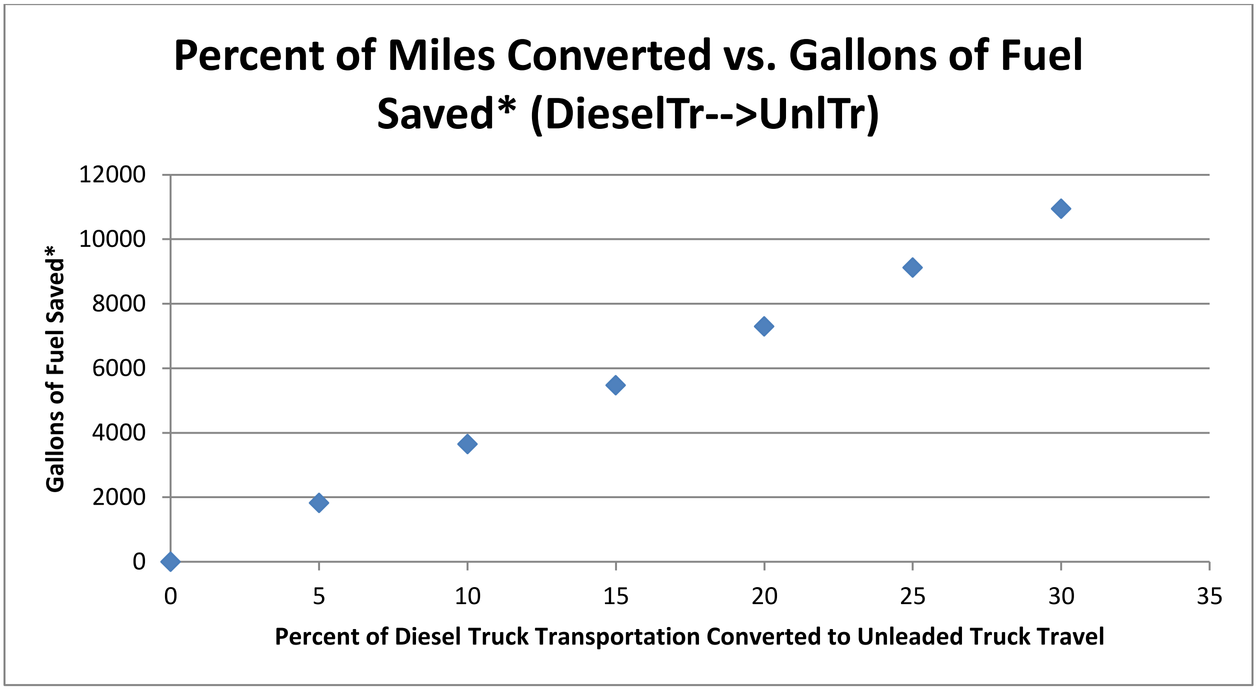


Figure 22- Graph representing the gallons of fuel that would have been saved based on the six years of data provided by converting diesel truck travel to unleaded truck travel from a 0% conversion to a 30% conversion. Asterisk denotes different energy contents of unleaded and diesel fuel.

The following charts show the calculations demonstrating the CO_2 savings with the previously described conditions.

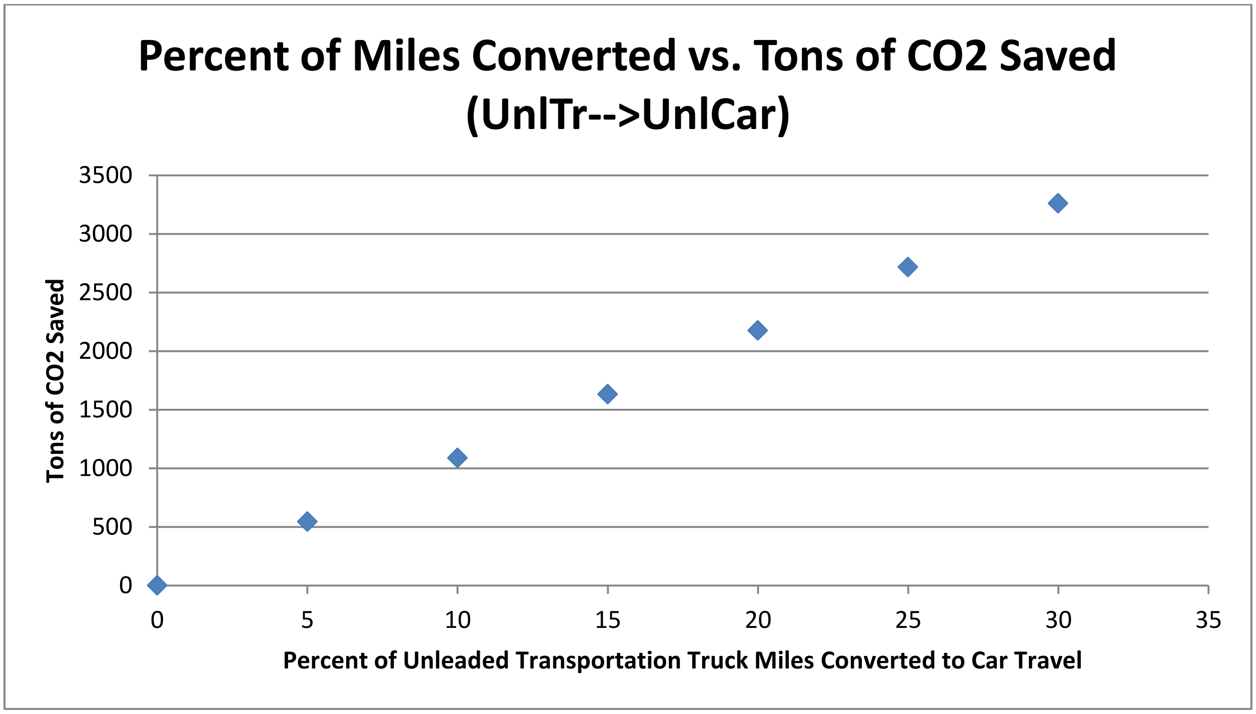


Figure 23- Graph representing the tons of CO_2 that would have been saved based on the six years of provided data by converting unleaded truck travel to unleaded car travel from a 0% conversion to a 30% conversion.

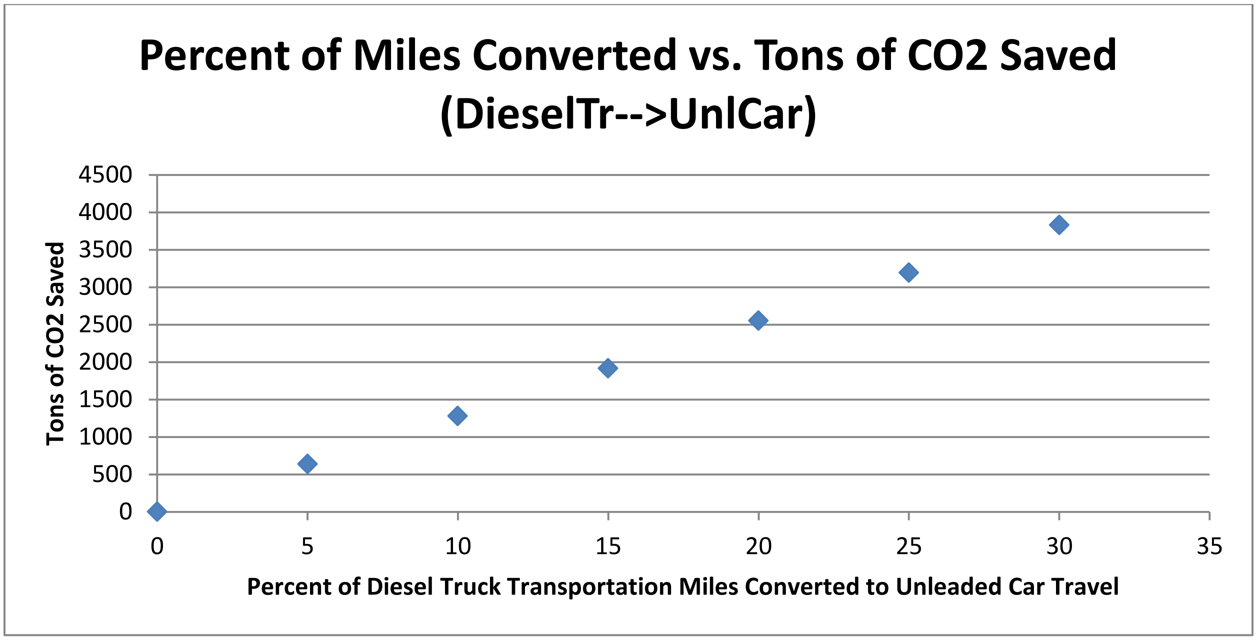


Figure 24- Graph representing the tons of CO_2 that would have been saved based on the six years of provided data by converting diesel truck travel to unleaded car travel from a 0% conversion to a 30% conversion.

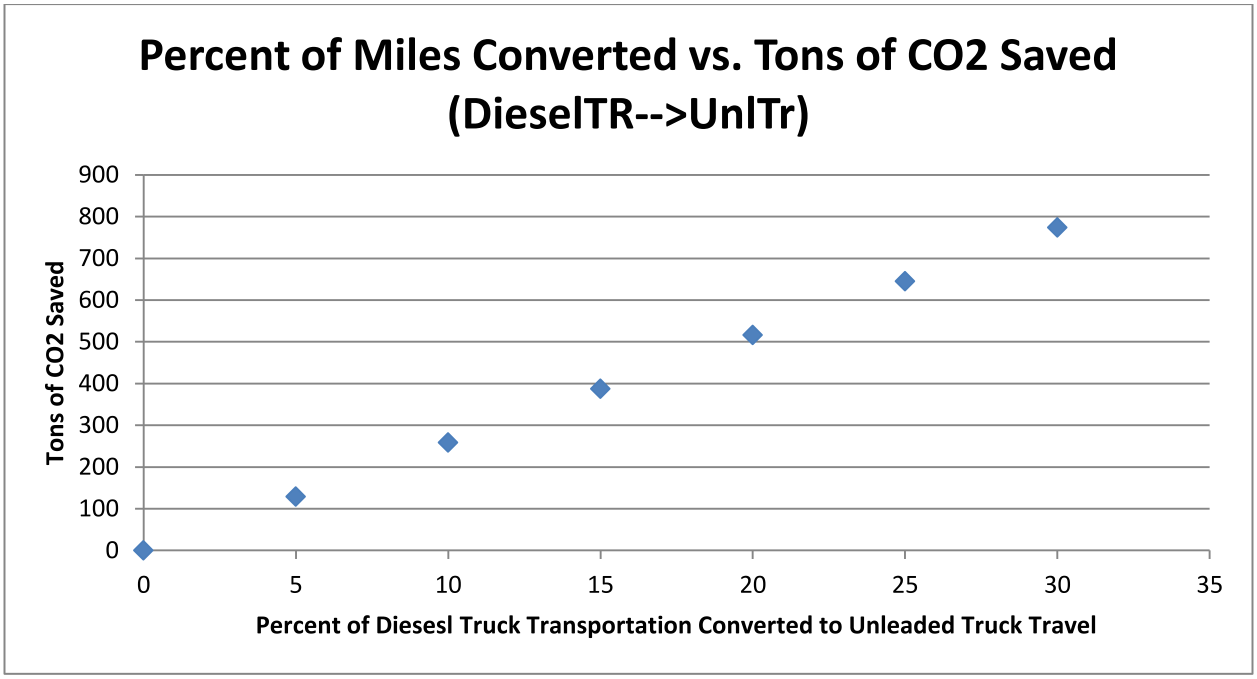


Figure 25- Graph representing the tons of CO_2 that would have been saved based on the six years of provided data by converting diesel truck travel to unleaded truck travel from a 0% conversion to a 30% conversion.

The charts below show analogous calculations but with monetary savings as the dependent variable.

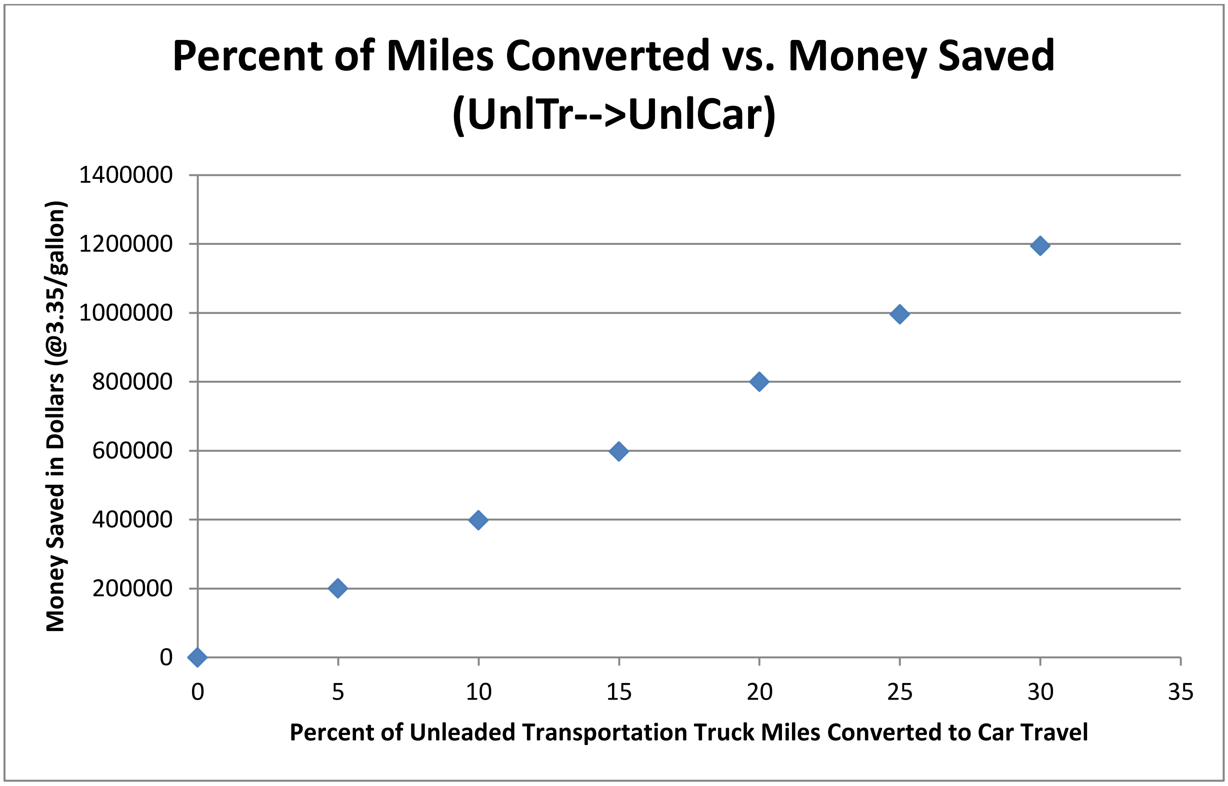


Figure 26- Graph representing the money that would have been saved based on the six years of data provided and $3.35/gallon of unleaded by converting unleaded truck travel to unleaded car travel from a 0% conversion to a 30% conversion.

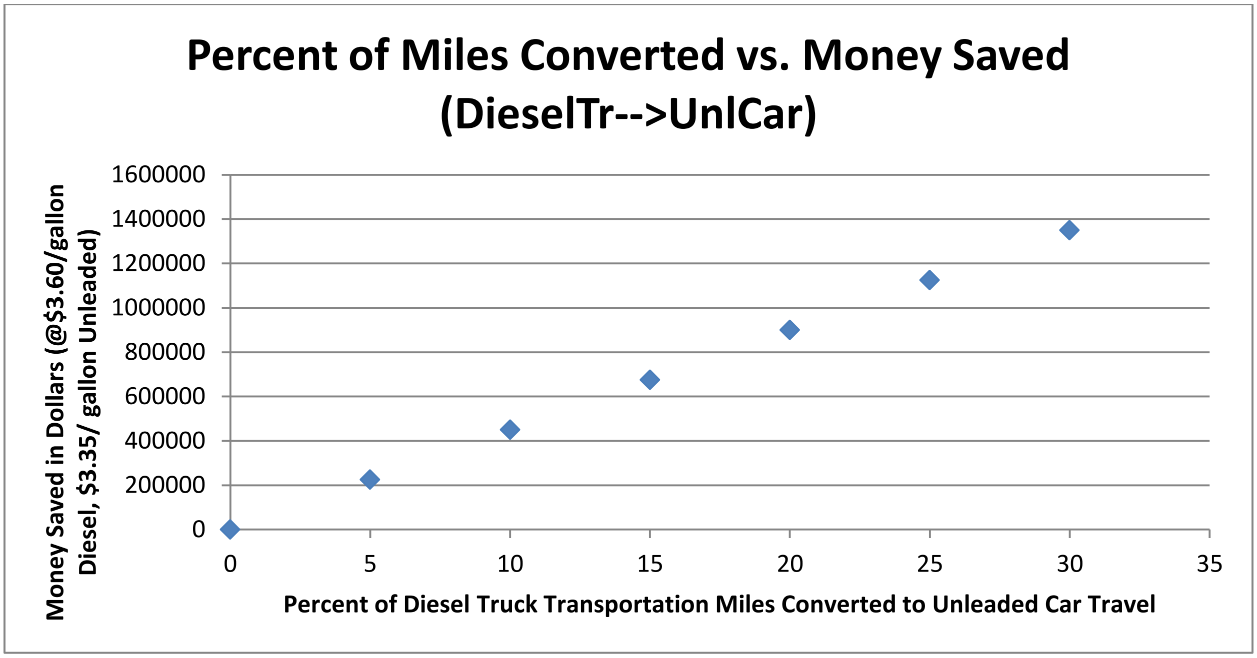


Figure 27- Graph representing the money that would have been saved based on the six years of data provided, $3.35/gallon of unleaded, and $3.60/gallon of diesel by converting diesel truck travel to unleaded car travel from a 0% conversion to a 30% conversion.

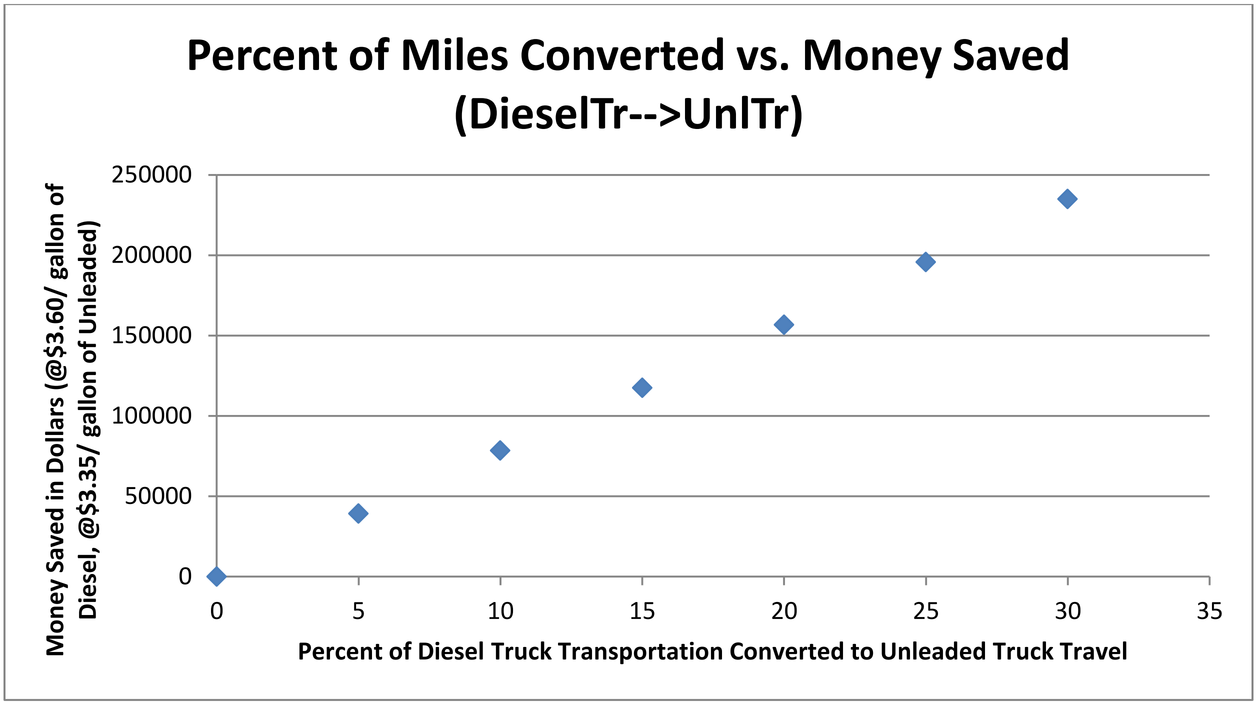


Figure 28- Graph representing the money that would have been saved based on the six years of data provided, $3.35/gallon of unleaded, and $3.60/gallon of diesel by converting diesel truck travel to unleaded truck travel from a 0% conversion to a 30% conversion.

It is apparent that the savings of converting diesel truck miles to unleaded truck miles is not nearly as great as converting the same miles to cars, but $150,000 and 500 tons of CO_2 is no small amount either. Any of the mileage conversions shown here that KDOT could succeed in executing at any percentage would be a step in the right direction with few to no drawbacks.

Biofuels

Biofuels are often discussed as a prominent option in today's sustainability and green movements. The two most common biofuels are ethanol and biodiesel. Ethanol is an alcohol that can be obtained many different ways but does not have a technical definition as a biofuel (NREL). Defining ethanol as a biofuel would not be plausible because of its widespread use across many different industries; ethanol is the alcohol in adult beverages as well as the active ingredient in many instant hand sanitizers. Biodiesel on the other hand, is technically defined as "a fuel comprised of mono-alkyl esters of long chain fatty acids derived from vegetable oils or animal fats, designated B100, and meeting the requirements of ASTM D 6751" where B100 is 100% biodiesel (i.e. B20 would be 20% biodiesel, 80% petroleum) (www.biodiesel.org). This definition will be expanded upon later.

The term "biofuels" is an appropriate name because, ultimately, fuels are obtained after a number of steps with the starting materials always originating in biological life. The biological origin of biofuels is the reason that they fall under the category of renewable energy since the supply can be regrown. Because of their renewability, they are a step in the right direction for sustainability and reducing the overall carbon footprint of internal combustion engines, as well as many other liquid petroleum devices.

Biofuels are not the miracle discovery that will solve all of the pollution problems in the world, however. Biofuel supporters are often met with the argument that the fuels still result in the combustion of organic molecules to produce CO_2 and water, just like petroleum products. While this is a valid argument, a larger picture must be considered, which in this case would be a full life-cycle analysis (LCA). As plants grow and develop, they produce biomass. Biomass is the general makeup of a plant, which is a complex mixture of proteins, lipids, and carbohydrates. It is these biomolecules that are converted into fuel for use in place of petroleum products. The plants and organisms used to make biofuels are photosynthetic, that is, they use sunlight and CO_2 to produce oxygen and biomass. The CO_2 in the atmosphere is largely from combustion and oxidation of fuels related to human activities. Since theCO_2 from these processes is taken from the atmosphere and fixed into the plants' biomass as a reduced, useable fuel, the carbon is, in a sense, recycled.

This means that if the full growth and development of the plants or organisms providing the raw materials for biofuel production is considered in the LCA, then these fuels are in fact renewable. To summarize, the carbon in more reduced organic molecules from plant matter is oxidized, burned, and converted to CO_2 which is then taken up by other photosynthetic organisms to be reduced back to energy yielding organic molecules and fixed in biomass, ready to be processed again as biofuel. Biofuels are not a truly carbon neutral solution, however, because the refining and combustion processes are not 100% efficient, and therefore waste some of the energy stored in the biomass. It is difficult to fully define the necessary inputs and outputs for a LCA due to its interdisciplinary nature, so quantification is highly variable and not yet reliable (Davis, Anderson-Teixeira et al. 2009). Figure 29 is presented to visually clarify the cycling of carbon from biomass to the atmosphere.

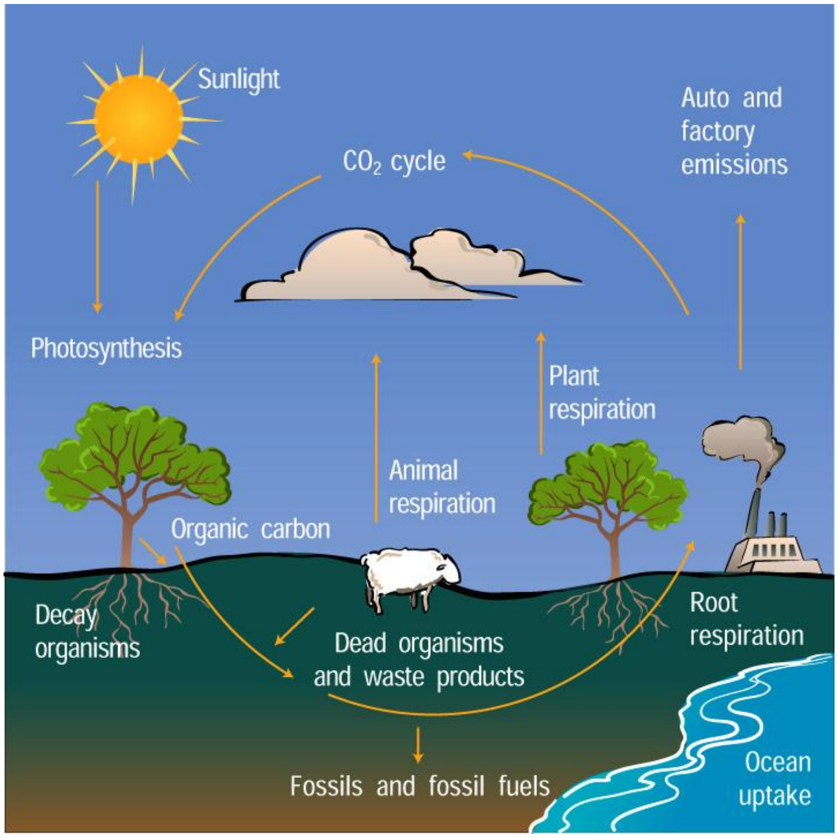


Figure 29- The Carbon Cycle, courtesy of ucar.edu

Considering the scope of this project and KDOT's vehicle fleet, it is more appropriate to address biodiesel than E85 so any further discussions in this paper of biofuels will be specific to biodiesel for KDOT's application unless otherwise noted.

There are a number of differences between petroleum diesel and biodiesel that contribute to the success or failure of its introduction to a vehicle fleet, but it is important to remember that neither one is a single molecule. Both types of diesel are highly diverse and complex mixtures of molecules, generally numbering between ten and nineteen carbons per molecule (http://www.atsdr.cdc.gov). The properties of each type of fuel are discussed below as the overall properties of the mixture with typical trends or common elements specifically discussed.

One of the chief differences between biofuels and petroleum fuels is the partial oxygenation of the biofuels. An elemental analysis of petroleum diesel shows that it is about 86% carbon and 13% hydrogen (Tat and Van Gerpen 1999). Because biofuels are made from biomass (lipids, carbohydrates), there is an inherent oxygen content due to the presence of oxygen in the structures of these biomolecules. An elemental analysis of biodiesel shows a breakdown of 76% carbon and 12% hydrogen, suggesting that there may be up to about 10% oxygen(Tat and Van Gerpen 1999). Generally, biodiesel is made from triglycerides which are converted into methyl or ethyl esters by a transesterification reaction. A general reaction for this conversion is shown below.

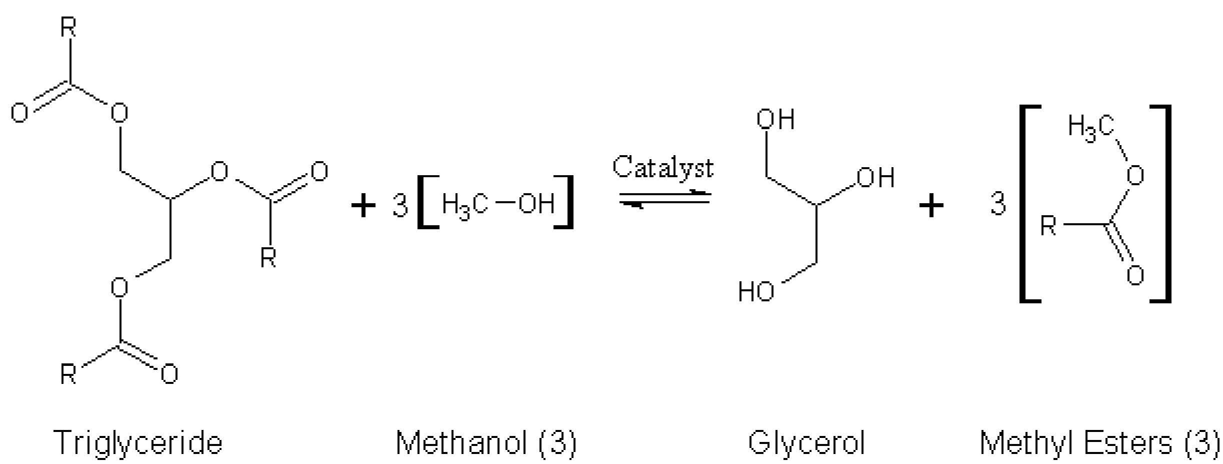


Figure 30- General chemical reaction for conversion of triglycerides (vegetable oils) to biodiesel and glycerol. Note: methyl esters are the final biodiesel product and the glycerol is separated and removed as a byproduct.

Image courtesy of [*http://en.wikipedia.org/wiki/User:Rataguera/draft*](http://en.wikipedia.org/wiki/User:Rataguera/draft)

The oxygen content is plain to see in this reaction, as it is necessary to allow the reaction to proceed at all. This inherent oxygenation, as with most things, has both a pro and a con. The benefit that it adds is more complete combustion. Since the fuel has oxygen distributed throughout its liquid makeup, there is not as high of a demand for molecular oxygen (O_2) from the atmosphere during combustion of the fuel. By lowering the atmospheric O_2 demand and keeping all other conditions the same, it becomes easier to fully combust the fuel to CO_2 and water, rather than failing to react completely. Incomplete combustion products such as carbon monoxide and unburned hydrocarbons are often more harmful and dangerous to the environment.

Lowering the atmospheric O_2 demand by increasing the internal oxygen content of the fuel also leads to the drawback of biofuels—lower heating value. The useable energy that comes from fuels is in the form of heat which is released in the oxidation and combustion of the fuel. If the fuel already has oxygen in it, or is more oxidized to begin with like biofuels, then there is less potential energy to release from subsequent oxidation when compared to its more reduced standard petroleum diesel counterpart (Tat and Van Gerpen 1999). This means that less energy is produced from the same fuel volume.

One additional benefit of using biodiesel in a blend is the restoration of lubricity. Petroleum diesel had always provided enough lubricity with its standard components until regulations recently required that sulfur content be greatly decreased; the sulfur in the petroleum diesel was the main source of lubricity. It has been found, however, that lubricity is restored to favorable levels even with very low level biodiesel blends, around 1% (Sadashivam 2007).

The biggest and most influential difference between biodiesel and petroleum diesel is viscosity. Viscosity is a measure of the internal friction of a fluid or how pourable that fluid is (CRC 2011). A highly viscous fluid is more like syrup while a fluid with low viscosity is more like water. Biodiesel has a higher viscosity which means that it is thicker. This thicker quality is the source of many of the issues surrounding biodiesel's introduction to the current infrastructure and equipment.

These problems are related to the fact that the fuel resists transport through a vehicle's fuel system. Fittings, gaskets, and pumps get plugged up with the thick fluid and prevent timely delivery to combustion chambers, often leading to more serious problems. There are a number of other minor differences as well, but they are ultimately related to the difference in viscosity. These problems include cloud point, pour point, and melting point. All three of these properties are closely related such that they are all temperatures in the melting or freezing process of the biodiesel. If the fuel cools to near its melting or freezing point, first it will become slightly cloudy as small crystals begin to form throughout the liquid (cloud point), then it will become too viscous to pour (pour point), and finally become a solid (melting point). Table 6 shows the cloud points for both petroleum and biodiesel. In most American climates, petroleum diesel's cloud point (-15°C to 5°C, 5°F to 41°F) is low enough that it does not necessarily introduce a huge issue, although winterization of ULSD is also common in northern climates. Biodiesel's cloud point (-3°C to 12°C, 27°F to 54°F), however, is in a temperature range that is commonly encountered in most areas. This is an example of why blending or winterization with kerosene is more important when considering biodiesel as a fuel.

These three points also show how temperature can affect viscosity; generally, as temperature increases, viscosity decreases (Gong, Shen et al. 2012). The viscosity of biodiesel can be attributed to its molecular structure. Theoretically, the raw oils from biomass, such as vegetable oil or olive oil, could be used as a fuel source. However, these oils are much more viscous than even biodiesel and are not a viable fuel for vehicles. Lowering the viscosity is the main reason for the transesterification reaction. The difference in viscosity is significant, changing from about 25 cSt as a triglyceride to about 4-6 cSt after the transesterification(Valeri and Meirelles 1997; Tat and Van Gerpen 1999), compared to a range of about 1.5-4 cSt for petroleum diesel (Sadashivam 2007).

The structure of the esters is still much simpler than the compounds found in petroleum diesel, however. The more complex branching and ring structures seen below (left) in a representative petroleum molecule prevents the molecules from becoming too packed together in a regular structure (Hong, Lam et al. 2011). Such a regular structure would have relatively low entropy which would present conditions conducive for forming crystals. The characteristic straight chain structure of biomass (below, right) allows for this closer packing of molecules and conditions such that crystals can be more easily formed, or at least always remain thicker in nature when compared to petroleum diesel (CRC Handbook). Further, the regular location of oxygen in the structure of the esters introduces some weak polar effects that also contribute to more regular structure and orientation of molecular interactions.

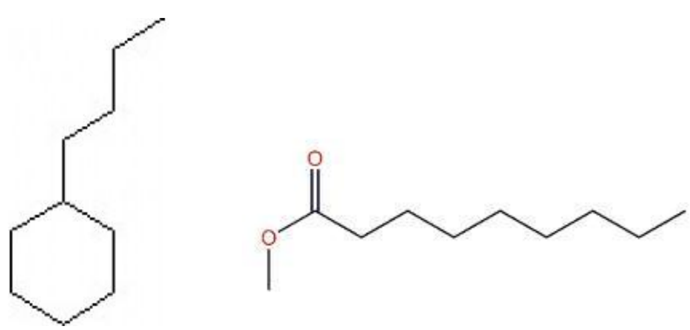


Figure 31- A typical petroleum diesel molecule (left) and a typical biodiesel molecule (right)

The differences in molecular structure affect how easily they can be brought together to form crystals. How easy or difficult it is for the molecules to come together is dependent upon how much energy is present to prevent them from becoming solids. The energy that allows or prevents melting or freezing is in the form of heat, which further demonstrates the importance of temperature on viscosity. The table below, adapted from (Sadashivam 2007) provides a snapshot of many of the properties already discussed.

Table 6- Various physical properties of petroleum diesel and pure biodiesel.

Fuel Property	Diesel	Biodiesel (B100)
Fuel Standard	ASTM D975	ASTM D6751
Lower Heating Value, Btu/gal	~129,050	~118,170
Kinematic Viscosity, @ 40°C	1.3-4.1	4.0-6.0
Specific Gravity, kg/l @ 60°F	0.85	0.88
Density, lb/gal @ 15° C	7.079	7.328
Water and Sediment, vol%	0.05 max	0.05 max
Carbon, wt%	87	77
Hydrogen, wt%	13	12
Oxygen, by dif. Wt%	0	11
Sulfur, wt%	0.05 max	0.0 to 0.0024
Boiling Point, °C	180-340	315-350
Flash Point, °C	60-80	100-170
Cloud Point, °C	-15 to 5	-3 to 12
Pour Point, °C	-35 to -15	-15 to 10
Cetane Number	40-55	48-65
Lubricity SLBOCLE, grams	2000 – 5000	>7000
Lubricity HFRR, microns	300 – 600	<300

Different structures in the molecules also affect how they combust. The typical petroleum diesel molecule shows a cyclic structure and can often be aromatic as well. Biodiesel molecules are straight chain molecules, generally alkanes with a small percentage of alkenes (Ma and Hanna 1999). Again, the more complex structure of petroleum diesel requires a more complex combustion mechanism, likely due to having to break the carbon rings and overcome the resonant stability of aromatics. This means that in a mixture of cyclic aromatics and alkanes, alkanes will combust more quickly and more completely (Broderick and Marnane 2002). Incomplete combustion of aromatics can result in the formation of soot (Glassman 1989). This means that increasing the presence of biodiesel (straight chain alkanes and alkenes) will decrease the occurrence of soot formation and incomplete combustion, raising the overall quality of combustion.

The simpler molecules of biodiesel are due to its biological origins. Organisms synthesize many of these molecules within their cells. Both energetic and enzymatic limitations favor a simpler structure to the complex, branched structures found in petroleum(Fickers, Marty et al. 2011).

Another property of biodiesel is its solvent ability; it readily dissolves most organics that it encounters. This can be useful if it is the intended use, but it can prove problematic in fuel systems. If there is any residue built up on the lines of a fuel system that has not been using biodiesel, then that residue will dissolve into the flowing liquid. Once these particles are in solution, it does not take long for the fuel filter to become clogged and need replacing. This problem is generally short-lived, however, and is no longer an issue once the system has been cleaned out by the biodiesel.

The materials used in the transport system are generally organic materials and are not exempt from the solvent ability of biodiesel. The most widespread and relevant example of material compatibility issues is natural rubber which was commonly used in vehicles before 1993 (NBB).The hoses and gaskets in the fuel transport system would rapidly break down after biodiesel was introduced. Vehicles produced after 1994 no longer use natural rubber in their fuel systems so the compatibility issue is not observed. These vehicles commonly use Teflon or Nylon in the fuel transport system (NBB). Other materials that can display negative effects of this solvent ability include neoprene, nitrile, and styrene (NBB). Metals can also present some compatibility issues although it instead accelerates the oxidation of the biodiesel itself instead of dissolving into the fuel. Specific examples of metals that should avoid direct contact with biodiesel are copper, zinc, and lead (which indirectly implies lead solder) (NBB).

Biofuels have been explored by a number of other states to varying degrees of success, mostly depending on climate since temperature plays a crucial role in the viscosity of biodiesel, as previously discussed(Sadashivam 2007).Biodiesel is almost always used in a blend with petroleum diesel in order to achieve a mixture of the different properties of the two fuels. The most common blends are 2% (B2), 5% (B5), 10% (B10), and 20% (B20). This is generally because the diesel systems employing the blends were designed for petroleum diesel use. By blending biodiesel so that the composition is still largely petroleum diesel, those properties dominate and minimize possible problems from the different properties of biodiesel. Also, some warranties are voided by using blends above a certain value.

Florida and Georgia are two state DOTs that use B20 through winter, but the warm climate keeps cold weather issues from surfacing (Sadashivam 2007). Other state DOTs that continue to use biodiesel year round include North Dakota, South Dakota, Minnesota, Iowa, and Ohio. Of these states, Ohio and Iowa reported cold weather issues including clouding and gelling (Sadashivam 2007). This is of particular interest to KDOT since Iowa and Ohio share similar winter weather patterns with Kansas. A survey of biodiesel retailers (locations unavailable) reported complaints of difficult cold-starting and excessive filter plugging with B20 blends in light to heavy duty trucks and farm equipment, although solvent ability could not be eliminated as a cause for filter plugging (Tang, Abunasser et al. 2008).

Since viscosity is the main concern, climate challenges can usually be overcome by adjusting the blend, with colder climates finding success by using a B2 or B5 blend(Sadashivam 2007). Additional solutions can include additives such as kerosene to overcome cold weather issues (NBB). These issues can also be avoided by keeping the fuel warm. Connecticut, Florida, North Dakota, and South Dakota achieve this by storing the fuel in underground storage tanks (Sadashivam 2007).

With the composition of biodiesel dependent upon its plant or animal source, different batches of biodiesel may have different physical properties including viscosity, melting point, heating value, and cetane number. The standard methods and values for approving each batch are set forth by the American Society for Testing and Materials (ASTM) in the method ASTM D6751 which is accepted as the industry standard. These standard values must be met before the fuel can be classified and distributed as biodiesel. Additionally, ASTM-D6751 is only applicable to pure biodiesel (B100) and says nothing about blends.ASTM-D7467-10 is applicable to biodiesel blends from 6%-20% (B6-B20), with the prerequisite of the initial biodiesel conforming to ASTM-D6751 and the petroleum diesel component conforming to

ASTM-D975. Considering the relatively small stores of pure biodiesel when compared to blends, it makes sense to have standards adaptable to blends.

The properties that ASTM-D6751 addresses are largely physical properties that do not typically change unless the chemical makeup of the fuel changes. Properties like cetane number, which is a rating of the combustion quality of diesel (analogous to octane rating in gasoline), will remain constant given a constant fuel composition. While it provides necessary minimums, the ASTM method neglects many crucial aspects that need to be considered for practical reasons, namely storage. Storing the fuel for varying periods of time can result in a change in the fuel composition and performance. Factors that contribute to altering the molecules can include temperature and light.

Many states have acknowledged the shortfalls of the ASTM method in regards to storage and have sought more appropriate testing and methods to ensure consistent quality over time. A new method of evaluating biodiesel, BQ-9000, was developed and is being endorsed by a number of states. The immense complexity of biodiesel allows for an equally immense number of things that can change or go wrong in long term storage of the fuel. This alternative evaluation of biodiesel takes into consideration much more than the minimum ratings of the ASTM-D6751, which serves as a backbone for BQ-9000's development (ASTM). The mission of BQ-9000 is to "promote public acceptance and to allow consumers to confidently buy biodiesel produced and maintained at the industry standard of ASTM-D6751" (NBAC 2011).

The BQ-9000 method not only sets forth requirements for many of these measurements, but also allows for labs, producers, and distributors to be "BQ-9000 Certified" (NBAC 2011). This type of certification makes it easy for state agencies and any other large-scale consumer to know that the product they are receiving is currently and will remain of the highest quality for a reasonable amount of time.

To become BQ-9000 Certified, a lab or producer must show results conforming to the standards of ASTM-D6751 for a minimum of seven batches produced from the same feedstock (NBAC 2011). If these requirements are passed, then the lab or producer can become BQ-9000 Certified which allows a reduction in testing requirements. The reduced testing requirements are known as “critical testing criteria” or “reduced specification” and must be performed on every batch (Fashian 2010). These criteria include either flash point or alcohol content, water and sediment, sulfur, cloud point, acid number, cold soak filterability, free and total glycerin, and oxidation stability (Fashian 2010). Full testing must still be produced in regular intervals, usually monthly, quarterly, or yearly (NBAC 2011). Additionally, if there is a significant change to the feedstock, then the producer must re-establish confidence in the production process with a minimum of three consecutive satisfactory batches. The most common significant changes are using different ingredients, different feedstocks, or changing equipment. Other significant changes are outlined in the full BQ-9000 standards (NBAC 2011).

BQ-9000 is helpful in addressing the regular testing of stored biodiesel to ensure quality over time and also expediting the purchase and production process once a producer is BQ-9000 Certified. Once a producer is certified, the tests take less time and fewer materials, lowering overhead costs which translate to quicker delivery and possibly a cheaper product. Overall, this program is successful in pursuing its goals of encouraging the growth of biodiesel production and consumption.

One issue not addressed by either ASTM-D6751 or BQ-9000 is microbial activity. Biological activity is possible in both petroleum diesel and biodiesel but to a much higher degree in biodiesel due to the natural origins of the molecules (Dodos, Konstantakos et al. 2012). The simpler molecules and oxygen content are more ideal for microbial inhabitants. The inherent oxygen content also contributes to biodiesel being slightly more unstable than petroleum diesel(NREL). Instability here refers to the ability of the fuel to oxidize and breakdown or polymerize over time without the introduction of any other chemicals or conditions, although higher temperatures decrease stability and lower biodiesel blends show increased stability (Shang, Lei et al. 2012). Periodic testing should be performed on any pure biodiesel or blends on site to ensure proper performance with a recommended maximum storage time of about 30-45 days and a maximum blend of B20 (Shang, Lei et al. 2012).

Conclusions/Recommendations

The work done in this study analyzed fuel and maintenance records in a Microsoft Access database. This analysis brought to light a few trends regarding MPG efficiency and fuel consumption that led to conclusions about possible solutions to reduce fuel consumption and, consequently, the financial burden and carbon footprint of KDOT. The database allows for continued analysis of newly added records identical those already maintained. The quality of the analysis in the database is only limited by the quality of the records added. However, the analysis itself is robust and can be applied to subsequent records given that those records are maintained according to the methods already employed. Any significant deviations from previous analyses should be attributable either to drastic changes in fuel trends or gross errors in record keeping. Continuing with these same record fields and the queries and reports already in place will provide an ongoing analysis similar to the results presented in this study.

The decreasing trends regarding fuel usage and miles traveled due to internal KDOT efforts that were noted in this study should be continued for as long as possible. The decreasing fuel usage trend can be further enhanced by "using the right tool for the job," that is, use cars rather than trucks for transportation whenever possible or unleaded trucks in lieu of diesel trucks if the workload allows it. Also, biofuels offer a separate avenue to reduce net CO_2 emissions by way of a life-cycle analysis without actually reducing total fuel usage. Biofuels should be employed at all times for E85 FFVs and in appropriate seasonal blends for diesel vehicles.

Kansas currently requires all state diesel vehicles to run on a B2 blend whenever biodiesel is no more than ten cents greater than petroleum diesel(Sadashivam 2007). While this is a low percentage, blends over B5 can introduce some of the problems already discussed when coupled with the cold winters in Kansas. Many other states with similar weather patterns can see these problems through the winter months if they do not take preventative measures like lower blends, additives, or engine block heaters (Sadashivam 2007).As far as storing the fuel, an underground storage tank maintains a necessary temperature through winter months (Sadashivam 2007).

Keeping these cold weather issues in mind as well as the cold winters in Kansas, preventive measures should be taken if biodiesel will be used through the winter months. If KDOT blends the biodiesel on site, blends of B10 should be the maximum biodiesel percentage for winter months with B5 preferred in the coldest portions. The B10 blends should also use kerosene as an additive in comparable concentrations to petroleum diesel winterizing steps. Blends up to B20 should be used in summer months.

Winterizing fuel introduces another possible issue in that there will ultimately be two different fuel types, summer and winter fuels. Winter fuels will perform just fine in warmer months since the viscosity will only continue to decrease with higher temperatures. Summer fuel, however, will be problematic in cold weather should it be left in a vehicle that has not been used for an extended period of time. Care must be taken by personnel to avoid these situations by regularly cycling through vehicles. Another reasonable guideline would be to fill winter-specific vehicles such as snow plows with only winterized fuel.

Incorporating higher biodiesel blends would also allow for the solvent properties of biodiesel to become an issue. To remedy any of these issues, an accelerated maintenance schedule would be advised. This would include regular fuel system inspections (fuel filter, lines) on a monthly basis for the first year that the higher blends are used. Catching clogging issues early will prevent subsequent catastrophic mechanical issues.

Storage of the biofuels would require a regular maintenance and inspection schedule to ensure proper performance from the fuel. Whether the biofuel is stored as a blend or in a pure form, it should be stored in an underground storage tank or a climate controlled facility, if possible. Also, the fuel should be inspected weekly for any obvious inconsistencies and tested biweekly with, at a minimum, the reduced specification criteria, in addition to testing upon receipt. Further, biodiesel should only be purchased from BQ-9000 certified producers or distributors. Current guidelines for ethanol purchase and blending will continue.

Biofuels are not generally in short supply in Kansas and surrounding states because of the large agricultural influence in the Midwest. KDOT purchasing biofuels produced from local farms sets a good fiscal example and stimulates local economies. Using biofuels is a great way to help lessen the impact of CO_2 footprint, even though it is only a step along the way toward a more fully sustainable energy supply. As mentioned before, it is not possible to reliably quantify the full effects of a LCA, but if the reasonable assumption of a net decrease is made, then biofuels make sense. Further, with the present fiscal guidelines when purchasing biofuels, there is no downside to increasing biofuel use in KDOT's fleet. The more KDOT can utilize biofuels, the easier the transition will be for private companies and individuals to make the same leap and reduce CO_2 emissions. Considering all of the facts and findings presented here, KDOT should continue to use biodiesel whenever possible and even try to increase their use with higher blends up to B10 or B20 when possible, such as summer months.

KDOT should also continue to use and maintain the Fuel Records Database developed in parallel with this project. Maintenance would be minimal and would only require the addition of the same records already kept in the monthly logs. The tools in the database will allow them to follow their trends and put the results toward making educated decisions in regards to their future, without further input from outside consultants. Monthly or quarterly reports generated from the database would also be helpful in the continuation and implementation of any programs or changes.

Possible future research could include similar analysis of other common pollutants produced by vehicles such as NO_x, total hydrocarbons, and particulate matter. Estimates for these pollutants are available similar to the ones used for CO_2 in this study (19.6lbs CO_2/gallon of unleaded, 22.4 lbs CO_2/gallon of diesel). Simple additions to the Fuel Records Database could produce these results similar to the figures already produced for CO_2.An analysis of these additional parameters would give a baseline for KDOT's production of these pollutants. Since these pollutants are directly related to fuel consumption and can produce adverse health effects in low concentrations (as low as about 5 ppm (OSHA 1997)), reducing fuel consumption can improve ambient air quality and promote respiratory health, particularly in urban environments or where KDOT activities are prevalent.

References

http://www.atsdr.cdc.gov/toxprofiles/tp75-c3.pdf

ASTM, American Society for Testing and Materials.

Berkeley_Labs "The Helios Project".

Broderick, B. M. and I. S. Marnane (2002). "A comparison of the C2–C9 hydrocarbon compositions of vehicle fuels and urban air in Dublin, Ireland." Atmospheric Environment **36**(6): 975-986.

CRC (2011). "CRC Handbook of Physics and Chemistry." (92nd Edition).

Davis, S. C., K. J. Anderson-Teixeira, et al. (2009). "Life-cycle analysis and the ecology of biofuels." Trends in Plant Science **14**(3): 140-146.

Dodos, G. S., T. Konstantakos, et al. (2012). "EFFECTS OF MICROBIOLOGICAL CONTAMINATION IN THE QUALITY OF BIODIESEL FUELS." Global Nest Journal **14**(2): 175-182.

EIA (2012). Gasoline and Diesel Fuel Update, U. S. Energy Information Administration.

EPA (2006). Ultra-Low Sulfur Diesel Timeline, Environmental Protection Agency.

EPA (2011). Greenhouse Gas Emissions from a Typical Passenger Vehicle, Environmental Protection Agency.

Fashian, M. (2010) "Defining Key Terms." Biodiesel Magazine.

Fickers, P., A. Marty, et al. (2011). "The lipases from Yarrowia lipolytica: Genetics, production, regulation, biochemical characterization and biotechnological applications." Biotechnology Advances **29**(6): 632-644.

Glassman, I. (1989). "Soot formation in combustion processes." Symposium (International) on Combustion **22**(1): 295-311.

Gong, Y. H., C. Shen, et al. (2012). "Viscosity and Density Measurements for Six Binary Mixtures of Water (Methanol or Ethanol) with an Ionic Liquid (BMIM DMP or EMIM DMP) at Atmospheric Pressure in the Temperature Range of (293.15 to 333.15) K." Journal of Chemical and Engineering Data **57**(1): 33-39.

Hong, Z. K., K. Y. Lam, et al. (2011). "A comparative study of the oxidation characteristics of cyclohexane, methylcyclohexane, and n-butylcyclohexane at high temperatures." Combustion and Flame **158**(8): 1456-1468.

Loris, N. (2009). EPA Formally Declares CO2 a Dangerous Pollutant. The Foundry.
Ma, F. R. and M. A. Hanna (1999). "Biodiesel production: a review." Bioresource Technology **70**(1): 1-15.
NBAC (2011). BQ-9000 Quality Management System, National Biodiesel Accreditation Commission.
NBB www.biodiesel.org, National Biodiesel Board.
NCDC Greenhouse Gases, National Climatic Data Center.
NREL, National Renewable Energy Lab.
OSHA (1997). OSHA Standards, Occupational Health and Safety Administration. **29 CFR 1910**.
Sadashivam, S. (2007). Best practices for implementing a biodiesel program, Rolla, Mo. : University of Missouri-Rolla.
Shang, Q., J. Lei, et al. (2012). "Production of Tung Oil Biodiesel and Variation of Fuel Properties During Storage." Applied Biochemistry and Biotechnology **168**(1): 106-115.
Tang, H., N. Abunasser, et al. (2008). "Quality survey of biodiesel blends sold at retail stations." Fuel **87**(13–14): 2951-2955.
Tat, M. E. and J. H. Van Gerpen (1999). "The kinematic viscosity of biodiesel and its blends with diesel fuel." Journal of the American Oil Chemists Society **76**(12): 1511-1513.
UNFCCC Global Warming Potentials, United Nations Framework Convention on Climate Change.
Valeri, D. and A. Meirelles (1997). "Viscosities of fatty acids, triglycerides, and their binary mixtures." Journal of the American Oil Chemists' Society **74**(10): 1221-1226.

Appendix A

Kansas Department of Transportation

Instructions for Using Microsoft Access "Fuel Records Database"

Notice: Be sure that all features are enabled in the database. A notification will appear just below the ribbon at the top of the page if all features are NOT enabled. Click to enable features if necessary.

It is very important that the names or titles of any tables, queries, reports, forms, or modules not be changed or altered in any way, despite typos or incorrect fiscal year dating!

Tables

The tables show all entries with all columns/fields included with no grouping or filters. The title of the table tells the specific entries that table shows. For instance, 2005 Deisel shows all entries and fields for any diesel vehicles beginning on July 1, 2005 even though it is fiscal year 2006 data.

All queries and reports will automatically update to include any records added to the tables they are linked with, although it may be necessary to save and close the table after new entries, and close and reopen the query or report to show newly added records.

The tables titled "All fueltype" contain all entries, with all fields and columns and no grouping, from all years in the database. "Date Corrected Query" is the master table with all entries, with all fields and columns and no grouping, from all fuel types and all years in the database, i.e. every entry in the database.

To total the data in a column in a newly created table, in the ribbon at the top of the page click the "Totals" button. This will bring up a row at the bottom of the table that will read "Total" to the far left of the row. Go to the column to be totaled (EUFUEL, EUTRMILE, EUUSDHRS) and click in the box to show a drop down button. Click the drop down button and then click "Sum".

Queries

The queries show much of the same data as the tables, but in a grouped and simplified view. They group entries together in some way to make trends or other helpful things apparent. Queries also show only immediately useful and relevant columns. There are a few additional calculated fields such as MPG.

The queries are divided by both fuel type and vehicle use, excluding ethanol (because of the small number of entries). For example, qryUnleadedMPG shows only unleaded entries while qryUnlTran shows only entries with unleaded fuel and a chief use of transportation. With the exceptions of DateDiff and %fuel queries, all query entries are grouped together by KDOT's internal vehicle ID number. These same queries are also set to only show vehicles with a total fuel use of at least 100 gallons. The subdatasheets in these queries break down the summarized entry with the individual data and additional columns from linked, parent tables or queries. These subdatasheets can be expanded to see more information for each group rather than having to search for records.

The %Totalfuel queries must be manually updated in design view. The percentage column is a calculated field that requires the total amount of fuel. The total fuel can be found in the bottom row of the "All fueltype" table with all of the totals. Enter the total amount of fuel in the design view (click at the top left, just under File, to enter design view) in the far right column, %Totalfuel. It should be entered between [SumOfEUFUEL]/ and *100.

Reports

The reports generate a summary of data linked to other tables or queries. These summaries include average, maximum/minimum, graphs, group statistics, etc. Reports with "Current" in the title are linked to queries that will show entries from a specified time period, chosen by the user. For instance, RptCurrentUnlMPG shows unleaded data from any time meeting the parameters set in the options of UnlDateDiff. Similarly, RptCurrentDieselMPG is linked to DieselDateDiff. Reports that do not have "Current" in the title are for all data entries of that fuel type and they are not customizable.

To set the time period, open the DateDiff query of the desired fuel type and open the design view by clicking at the top left of the page. Scroll all the way to the right to the column DateDiff. In the criteria row, the time is selected by number of months only. To see all entries between the current date and a number of months back, put "<=#" where #=the number of months. To see the entries with the updated time specifications, click at the top left again to return to datasheet view.

To show a time period where the current date is not one end of the period, in the criteria row, enter "<=$\#_1$ and >=$\#_2$" where $\#_1$=the number of months from the earliest date to the current date and $\#_2$=the number of months from the most recent date to the current date. For example, if the date is August 1, 2000 and I want to see data from the first half of that year only, the entry in the criteria row would be "<=7 and >=1" to show all entries between January 1, 2000 and July 1, 2000.

Adding external files to the Microsoft Access Database

To add an external Microsoft Excel file, click on the external data tab on the ribbon and then click the Excel button. The wizard will guide you through the upload and ask appropriate questions to ensure addition in the proper tables. Files can either be added as their own new table or added to an existing table.

Notice: If adding a new fiscal year's data to the database, the process must be repeated three times; one time to create or update an individual table for that year and fuel type, one time to add the entries to the "All fueltype" table, and one time to add the entries to "Date Corrected Query".