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Kansas Department of Transportation Enterprise Energy and Carbon Accounting and Utility Usage Research Phase 2B: Improving Energy and Fuel Efficiencies in KDOT Operations

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16 Abstract

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Using the compiled data from Phase 1 of this project (site location, buildings, energy use, and building square footage), a web-based database was developed to manage information on the energy use and embodied energy of KDOT campuses and individual buildings. This database can be used to identify trends of campuses to find under-performing buildings, to aid in the tracking of high performance buildings, and also aid in verifying the upgrading of inefficient systems originally found by comparing the database with EIA baseline values. An operational energy use simulator (online at http://www2.ku.edu/~sims/cgi-bin/KDOT/index.php) was also developed for KDOT's long-term meter tracking use. This system can show energy use by the state, district, city, county, and zip code. Using these tools and compiled records from the Phase 1 survey, we developed recommendations for projects to improve KDOT's energy efficiency and sustainability. These projects include LED fluorescent bulb replacements, retrofitting and upgrading existing HVAC systems to demand-controlled ventilation (DCV) systems, the use of lower embodied energy materials in new building projects, and changes in employee habits to conserve energy.

Fuel use by KDOT from fiscal years 2006-2011 was analyzed using a Microsoft Access database created 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 over this time period, but an increase in diesel use over the past several years. 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. This is most likely due to increases in engine capacity and fuel consumption for similar model vehicles over the past decade. Using more efficient means of transportation can significantly decrease KDOT fuel demand, in particular replacing truck travel with car travel where possible. The report also outlines specific advantages and disadvantages of more extensive biodiesel use to meet federal renewable fuel requirements, and recommends specific actions to address potential issues that could arise due to biodiesel compatibility problems with some materials and difficulties in cold weather operation.

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THE KANSAS DEPARTMENT OF TRANSPORTATION
TOPEKA, KANSAS

and

THE UNIVERSITY OF KANSAS
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PREFACE

The Kansas Department of Transportation's (KDOT) Kansas Transportation Research and New-Developments (K-TRAN) Research Program funded this research project. It is an ongoing, cooperative and comprehensive research program addressing transportation needs of the state of Kansas utilizing academic and research resources from KDOT, Kansas State University and the University of Kansas. Transportation professionals in KDOT and the universities jointly develop the projects included in the research program.

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Abstract

Reducing the environmental impact of facilities and operations has become an important function for many organizations. In many cases, such as utility and fuel use, reducing these impacts can also be coupled to financial savings. The Kansas Department of Transportation (KDOT) has determined that conducting an energy and CO_2 audit of its building and vehicle fleets will aid in assessing KDOT energy use, prepare for any future regulations regarding CO_2 emissions, and help identify areas for increased savings through reduced use of commercial resources (primarily energy and fuel). Phase 1 of this project established baseline carbon and energy data from three major sources: the total energy embodied in the construction, operation and repair of KDOT-owned buildings, the total energy embodied in KDOT use of utilities (electricity, water and natural gas) and the energy expended in the operation of KDOT's vehicle fleet and other associated equipment. The work covered in this report (Phase 2) focused on streamlining and improving access to this information, improving KDOT's ability to track their data, and identifying areas for reducing expenditures on energy and fuel. Related Phase 2 work by Kansas State University Transportation Center to conduct energy audits of KDOT buildings is described separately in a report from that institution (published as K-TRAN: KSU-12-5).

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Acknowledgements

The authors wish to acknowledge the financial support of the Kansas Department of Transportation (KDOT) for this research. The assistance of Leif Holliday, Peter Carttar, and Mark Clements in obtaining the utility account numbers and building plans was invaluable. Peter Carttar assisted the research team by providing and sending the letters to the utility companies requesting information on KDOT energy usage. Leif Holliday was the project monitor. Jeremiah Johnson, a MS student in the University of Kansas Environmental Engineering program who participated in the Phase I project, and Andy Carey also contributed significant time and effort to the development of the fuel database.

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Project Introduction and History

This work represents the second phase of a two-year project commissioned by the Kansas Department of Transportation (KDOT) and carried out by researchers in the Department of Civil, Environmental and Architectural Engineering at the University of Kansas. The primary goal of this work was to conduct an energy and CO_2 audit of KDOT's existing infrastructure. The impetus for this audit was twofold. At the time of the initial project proposal, there was a significant likelihood of changes to existing federal laws that would require the state of Kansas, and specifically the KDOT, to report, account for, and propose solutions to reduce carbon emissions. One major goal of this project was therefore to acquire the necessary data to calculate a baseline level for KDOT CO_2 emissions and develop KDOT's internal capabilities for carbon accounting. Through this process, KDOT could assess current CO_2 emissions levels, obtain credit for any reduction in those emissions due to changes in operation over the next few years, and begin planning solutions to reduce the agency's carbon emissions. For the purposes of this project, KDOT infrastructure and activities included in this audit included three major parts: the total energy embodied in the construction, operation and repair of KDOT-owned buildings, the total energy embodied in KDOT use of utilities (electricity, water and natural gas) and the energy expended in the operation and upkeep of KDOT's vehicle fleet and other associated equipment. (Road construction activity was specifically excluded from this study due to the difficulties of properly assessing the role of external contractors.) This baseline CO_2 audit was completed (with some data gaps) in Phase 1 of this project, and the results are available in report K-TRAN KU-11-2 (Kwok et al. 2012).

Most CO_2 production occurs as either a direct or indirect result of energy use, such as fuel combustion in an engine or power generation to provide lighting for a building. As a result, the data collection required to determine the CO_2 baseline audit also provided substantial information on ongoing KDOT energy use. At the conclusion of Phase 1, the project group has collected in one place information on KDOT infrastructure and operations ranging from design records and blueprints to utility data for KDOT facilities and agency-wide diesel and gasoline fuel consumption data. In addition, the research team had established methods for organizing this information into a searchable and accessible format and conducting energy and CO_2 calculations.

In particular, several databases were established that contained information on KDOT-owned facilities (building layouts, construction materials and utility use) and equipment (vehicle types, mileage and fuel consumption data). The research group had also developed models to estimate energy and utility use at smaller KDOT facilities where complete data are not available.

Over the past decade, energy and utility prices have increased substantially. As a result, energy use reductions have become a substantially more critical issue with respect to cost savings and efficient use of available funds. The implementation of more energy efficient practices in building operations and in the vehicle fleet has the potential both to free up resources for other urgently needed projects and for additional long-term savings. The databases and models developed for the first phase of this project represent both a potentially effective tool to allow KDOT to continue to monitor energy use and CO_2 emissions beyond the timescale of this project and a way to identify opportunities for energy reductions and cost savings. The second phase of this project, therefore, had two major objectives. The first was to develop the preliminary databases into analytical tools that could be used by KDOT beyond this project to track energy and fuel use and calculate CO_2 emissions for any future reporting requirements. The second was to find recommendations to lower the KDOT's direct (utility) energy use in their buildings and vehicle fleet based on our existing data.

As the methods to accomplish these goals depend on the specific types of energy use and information available, separate paths and techniques were used to assess building and vehicle fleet energy use. For KDOT-owned buildings, the analysis was facilitated by the creation of a database to monitor KDOT's utility energy. This database will aid in finding buildings that are using more energy than the established baseline that was produced during Phase 1 of this project. In the long-run a modified version of this can be used by KDOT to target inefficient buildings that need to have new, sustainable system upgrades to make the building on-par or better than other buildings or agencies. On the vehicle side, an existing database for monitoring fuel consumption by vehicle type was used to assess trends in fuel use and suggest actions for efficient operation. An examination was also conducted to assess the potential advantages and drawbacks to increasing KDOT's use of renewable fuels, particularly biofuels, as petroleum fuel substitutes. The results of this assessment are provided in this report. Chapters 1 through 3 describe the methodology, data, and results for the building and utility assessment, while Chapters 4 and 5 address vehicle fleet fuel use and the potential for biofuel adoption.

Chapter 1: Embodied and Operational Energy and Carbon in Buildings

1.1 Background

A recent report released by the International Energy Agency (IEA) estimated that if the current growth of energy production is not reversed, and the efficiencies in buildings and transportation are not improved, climate change will become irreparable in 5 years. The report also stressed the need to develop global solutions to reduce carbon production within a short timeframe, and the equal importance of legislative, social and economic reform (Harvey 2011). Thus, reducing energy use and carbon emissions would require both economic and social changes. Information and models of energy consumption and carbon emissions should be disseminated and communicated in such ways that government agencies, economic communities and the general public can easily understand the rationale for reducing their energy consumption and carbon emissions though cost saving measures. The question becomes then, what practices of sustainability are actually viable in reducing carbon output while still being more economical than other systems, how to target inefficent systems, and how to verify the new system's effectiveness.

Sustainability is the practice of replacing resources that are used. Finite resources, when used and discarded, reduce their availability for future use. Combining this with projected future population increases, humanity will by necessity need to use both less resources in total and per person. As individual resources become scarcer, their cost will increase. While this in itself will also limit their use, the negative economic effects will be significant, possibly causing an economic depression on a global scale. This problem can be avoided if sustainability measures can be used to reduce our dependence on specific limited resources, either through conservation or utilization of alternate materials. This practice, particularly the methods for reducing resource use and choosing substitute materials, can be seen as sustainable development.

Sustainable development is based on a three-tier system: economic, societal, and environmental sustainability (U.N. General Assembly 2005). Economic sustainability is the practice of using resources in the most efficient manner to yield the most economic gain. This practice is used in economic systems around the world. When the cost of a resource goes up due to lower availability, the markets using that resource find ways to use the resource more efficiently. However, this system is only sustainable when marketplaces function effectively and there are suitable alternative materials available. Societal sustainability is the practice in which society is renewed and strengthened. Ecological sustainability is the efficient use and replacement of resources. This tier is the necessary picture to be developed for full sustainable development. Ecological sustainability has been embraced in two ways, through resources management and consumption management. Resources management is the act of regulating the renewal and use of resources. This system is used in such industries as logging and agriculture, allowing for the continued replacement of harvestable resources. Consumption management is where the processed resources are managed in a way to increase the efficiency of the resource yield. Although these methods have been used in the past, they are currently gaining more significance as limits on resource availability become apparent. The key issue is how best to combine these three tiers to produce economically, societally and ecologically sustainable development both now and in the future. In this work, the emphasis is on accurate calculation and comparison of both embodied energy (based on building materials) and energy used in building operation, primarily utilities.

1.2 Building Energy Use

Phase 1's work involved organizing KDOT's 948 buildings into 54 separate building types. These building types are categorized by their use, construction, size, material, age, and other such methods. Table 1.1 shows the building types and their quantities.

TABLE 1.1
Building Type Organization

Building Type	Description	Number of Buildings
A1	Chemical Domes: Standard, Dome, and Cone	209
B4	Wash bays	89
C5	Equipment Storage, 4 Bay, less than 2000 ft^2	9
D6	Equipment Storage, 6 Bay, 2000 to 4000 ft^2	13
E7	Equipment Storage, 10 Bay, 4000 to 6000 ft^2, Open Side	43
F8	Equipment Storage, 6000 to 8000 ft^2	55

G9	Equipment Storage, 8000 to 10000 ft^2, Open side	8
H10	Area Office, 2000 to 4000 ft^2	4
I11	Area Office 4000 to 6000 ft^2	18
J12	Area Office 6000 to 8000 ft^2	3
K13	Area Office 8000 to 10000 ft^2	1
AA14	Storage Salt Bunker (Unused)	111
AA15	Storage Salt Loader (Unused)	79
L17	Sub Area 2000 to 4000 ft^2	69
M18	Sub Area 4000 to 6000 ft^2 Garage portion	31
N18	Sub Area 4000 to 6000 ft^2	31
O19	Sub Area 6000 to 8000 ft^2 Garage portion	6
P19	Sub Area 6000 to 8000 ft^2	6
Q20	Sub Area 8000 to 10000 ft^2	8
R21	Transmission Tower	1
S22	Storage less than 2000 ft^2	83
T23	Storage 2000 to 4000 ft^2	10
U24	Storage 4000 to 6000 ft^2	4
V25	Storage 6000 to 8000 ft^2	3
W26	Storage 8000 to 10000 ft^2	1
X27	Weighing Station	5
Y28	Loader Storage	11
Z29	Old District Shop	3
2A30	New District Shop	3
2B31	Laboratory less than 2000 ft^2	6
2C32	Laboratory 2000 to 4000 ft^2	4
2D33	Laboratory 4000 to 6000 ft^2	2
2E34	Laboratory 6000 to 8000 ft^2 Garage	1
2F34	Laboratory 6000 to 8000 ft^2	1
2G36	Laboratory Larger than 10000 ft^2	2
2H33	District Office District 3	1
2I38	District Office District 1	1
2J39	Construction Office District	0
2K40	Salt Brine	2
2L41	Radio Shop	3
2M42	District Office District 2	1
2N43	District Office District 5	1

2O44	District Office District 4 and 6	2
2P45	Warehouse District 2	1
2Q46	KHP HQ/Construction D6 D2 Annex	1
2R47	KHP Office District 3 & 5	1
2S48	KHP Office District 4	1
2T49	HDQ Material Laboratory, Topeka	1
2U50	Geology Laboratory, Topeka	1
2V51	KHP District 1	1
2W52	Area Office District 1	1
2X53	Area Office District 1 Olathe	1
2Y54	Metro Office Shop Construction	1
2Z55	Conference Room/Storage (Kansas City)	1
AA56	Stock Room (Unused)	1
AA57	Underground Concrete Blocks (Unused)	1

(Source: Kwok et al. 2012)

This organizational structure was used to make a baseline energy use estimate on a per year basis, using data from the United States Energy Information Administration's (EIA) Commercial Building Energy Consumption Survey (CBECS). CBECS is a large-scale survey of commercial buildings throughout the United States. This survey includes factors for many variables present in the operation and construction of the building (U.S. Energy Information Administration 2010). These factors were used to find baseline yearly energy use for each type of building; sample factors used in our calculations are shown in Figure 1.1 below.

Building Type	**2A-30**
	Energy Factor (Percent)
Building Floorspace (Square Feet)	
10,001 to 25,000	75
Principal Building Activity	
Service	86
Census Region and Division	
Midwest	
East North Central	
West North Central	89

Climate Zone: 30-Year Average	
Under 2,000 CDD and --	
More than 7,000 HDD	
5,500-7,000 HDD	
4,000-5,499 HDD	110
Fewer than 4,000 HDD	
Number of Floors	
One	83
Weekly Operating Hours	
Fewer than 40	
40 to 48	1
Ownership and Occupancy	
Government Owned	
Federal	
State	150
Local	
Predominant Exterior Wall Material	
Brick, Stone or Stucco	
Concrete (Block or Poured)	100
Concrete Panels	
Siding or Shingles	
Metal Panels	
Window Glass	
Other	
No One Major Type	
Predominant Roof Material	
Built-Up	110
Shingles (Not Wood)	
Metal Surfacing	
Synthetic or Rubber	
Slate or Tile	
Wooden Materials	
Concrete	
Other	
No One Major Type	
Percent of Floorspace Heated	
Not Heated	
1 to 50	
51 to 99	

100	115
Percent of Floorspace Cooled	
Not Cooled	
1 to 50	
51 to 99	
100	124
Percent Lit When Open	
Zero	
1 to 50	
51 to 99	106
100	
Percent Lit When Closed	
Zero	72
1 to 50	
51 to 100	
Lighting Equipment Types (more than one may apply)	
Incandescent	
Standard Fluorescent	113
Compact Fluorescent	
High Intensity Discharge	
Halogen	
Other	
HVAC Conservation Features (more than one may apply)	
Variable Air-Volume System	
Economizer Cycle	
HVAC Maintenance	
Energy Management and Control System (EMCS)	
Window and Interior Lighting Features (more than one may apply)	
Multipaned Windows	112
Tinted Window Glass	
Reflective Window Glass	
External Overhangs or Awnings	
Skylights or Atriums	
Daylighting Sensors	
Specular Reflectors	

Electronic Ballasts	
Energy Management and Control System (EMCS) For Lighting	
Total Average Per Building (kWH/ft^2)	22.1

(Source: U.S. Energy Information Administration 2010)

FIGURE 1.1
Example Factors for Building Type 2A-30

During the baseline assessment, there were certain campuses that were consuming much more energy than the EIA estimate would indicate. These campuses were put on a 'red flag' list to be analyzed during Phase 2 for causes of this high energy use and possible methods for reducing their consumption rates.

Several limitations are present in this overall assessment. Currently, there is no available information from KDOT District Three and Six due to the elapsed time frame and incomplete records available from the local power companies. Other districts have the information connected to individual campuses. A campus in this instance is where all the power meters are related to a single set of addresses that are adjacent each other. The issue that remains from the Phase 1 report is that a single meter sometimes is connected to multiple buildings and/or site lighting. Specific building meter connections were not obtained due to the complexity and set time frame of the project, thus limiting the energy review to campuses as the smallest review sites.

1.3 Energy Review

The American Society of Heating, Refrigerating, and Air Conditioning Engineers, Inc., (ASHRAE) created a standard for new construction and additions to buildings that specifically deals with the operational energy of a building. This standard is ASHRAE 90.1 ‘Energy Conservation in New Buildings Except Low-Rise Residential Buildings’ (ASHRAE 2012). This standard attempts to increase the energy efficiency of buildings by 30% compared to the International Energy Conservation Code. This standard, when enforced by the Authority Having Jurisdiction (AHJ), sets the maximum energy use of each building system that is installed. In the

State of Kansas, there is a unified enforcement of energy standards, meaning that each AHJ (e.g. City, County) enforces the codes in their area. Even though the ASHRAE 90.1-2004 is enforced in all areas of Kansas, ASHRAE 90.1-2010 would be an effective, cost-saving starting point to reduce KDOT's building utility use. The key differences between ASHRAE 90.1-2004 and 2010 include: (1) Additional 30% energy saving potentials (only includes major building categories); (2) Building façade and fenestration insulation assumptions have been adjusted to better reflect reality; (3) Additional compliance options that change the prescriptive approach into an option and the inclusion of trade off option; (4) Adjustments to the compliance standards for R-value, U-factor, C-factor, or F-factor for the entire assembly; and (5) Modifications made to the simplified approach for Heating, Ventilation, Air-conditioning and Refrigeration modeling method.

ASHRAE 90.1's sections are divided into what building systems are affected such as building envelope, HVAC, water heating, and lighting. Section 5 is used to increase the efficiency of the building envelope. The building envelope is the part of the structure that separates the interior of the building from the outside (e.g. exterior walls, floors, roofs, skylights, windows, doors, etc.). One of the methods required in this section (Section 5.4) is to reduce the infiltration/exfiltration in the envelope. The reduction of infiltration means that less unconditioned air is introduced into the building. Section 5.5 sets a minimum U value (the overall heat transfer coefficient), for building materials in the building envelope, reducing the amount of heat loss though the envelope itself. These methods aid in lowering the needed heating and cooling load of the building.

Section 6 deals with Heating, Ventilation, and Air Conditioning systems (HVAC). Sections 6.3 and 6.4 define the minimum efficiencies of HVAC systems in different climate areas. Section 6.3 is the simplified method of HVAC efficiency, which is shown in Figure 1.2.

The simplified approach option shown in Section 6.3 would be used for many of KDOT's smaller buildings. Over 95% of the set building types can conform to the requirements that are listed. The other buildings would have the use the more complex system shown in Section 6.4. Section 6.4.3 requires that the HVAC systems have automatic controls that will shut down the system when the building isn't occupied. The air ducts that supply the conditioned air have to be insulated, to reduce heat loss.

6.3 Simplified Approach Option for HVAC systems

6.3.1 Scope. The simplified approach is an optional path for compliance when the following conditions are met:

a. building is two stories or fewer in height

b. *gross floor area* is less than 25,000 ft^2

c. each HVAC system in the building complies with the requirements listed in Section 6.3.2

6.3.2 Criteria

a. The system serves a single HVAC *zone.*

b. The equipment must meet the variable flow requirements of section 6.4.3.10.

c. Cooling (if any) shall be provided by a unitary packages or split-system air conditioner that is either air-cooled or evaporatively cooled with *efficiency* meeting the requirement shown in Table 6.8.1A (air conditioners), Table 6.8.1B (heat pumps), or Table 6.8.1D (packaged terminal and room air conditioners and heat pumps) for the applicable equipment category.

d. The system shall have an air economizer meeting the requirements of section 6.5.1.

e. Heating (if any) shall be provided by a unitary packages or split-system heat pumps that meets the applicable *efficiency* requirements shown in Table 6.8.1B (heat pumps) or Table 6.8.1D (packaged terminal and room air conditioners and heat pumps), a fuel-fired furnace that meets the applicable efficiency requirements shown in Table 6.8.1E (furnaces, dust furnaces, and unit heaters), an electric resistance heater, ore a baseboard system connected to a boiler that meets the applicable efficiency requirements shown in Table6.8.1F (boilers).

f. The system shall meet the exhaust air energy recovery requirements of Section 6.5.6.1.

TABLE 6.3.2 Eliminate Required Economizer for Comfort Cooling by Increasing Cooling Efficiency

Climate Zone	Efficiency Improvement[a]
2a	17%
2b	21%
3a	27%
3b	32%
3c	65%
4a	42%
4b	49%
4c	64%
5a	49%
5b	59%
5c	74%
6a	56%
6b	65%
7	72%
8	77%

[a] If a unit is rated with an IPLV, IEER, or SEER then to eliminate the required air or water economizer. The minimum cooling efficiency of the HVAC unit must be increased by the percentage shown. If the HVAC unit is only rated with a full load metric like EER or CDP cooling the these must be increased by the percentage shown,

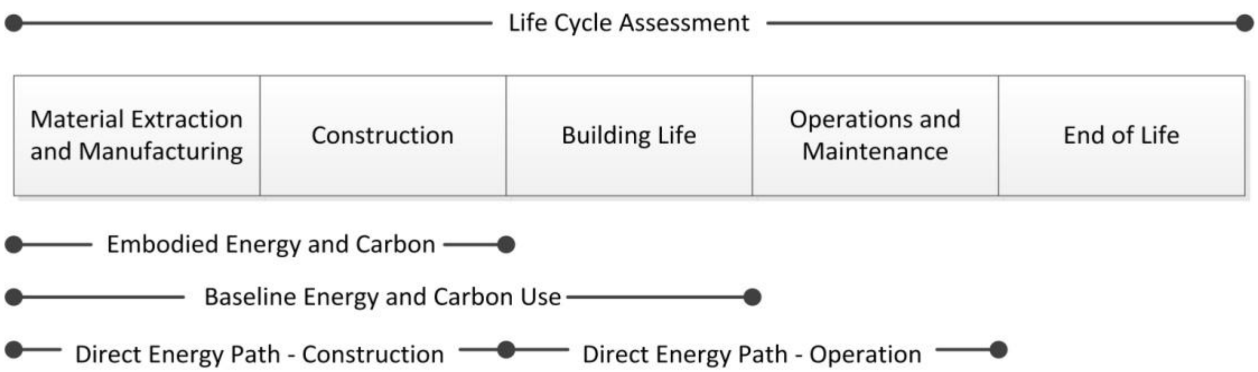
(Source: ASHRAE 2012)

FIGURE 1.2
ASHRAE 90.1-2012 Section 6.3

Section 9 of ASHRAE 90.1-2010 addresses energy conservation in regards to lighting systems. Lighting power density is mandated in section 9.5-6. The lighting power density is the maximum amount of luminaire wattage per square foot. This can be done by the building area method, or the space-by-space method. The building area method is where the use of the whole building defines a lighting power density (LPD) for the whole interior of the building. The space-by-space method defines the LPD by the use of the space. The space-by-space method is more accurate for power conservation, resulting in lower utility use.

1.4 Database

To aid in finding under-performing sites, or sites that are consuming energy at a higher rate than estimated, a database was designed. The purpose of this database is to monitor the life cycle energy use of the KDOT campuses. The life cycle is the total energy use of the building from the production of building materials (Embodied Energy), to the lifetime utility use



Life Cycle Energy Chart

The embodied energy was calculated in the Phase 1 report (K-TRAN: KU-11-2), and the full specifics of these calculations will not be addressed here. The operational energy database can be used to search campuses by full state total, district, county, city, or zip code. In this manner, the database can be used to identify trends of campuses to find under-performing buildings, to aid in the tracking of high performance buildings, and also aid in verifying the upgrading of inefficient systems that were originally found by comparing the database with EIA baseline values, as shown with the database shown in a later chapter. A high performance building is a project that aims to find methods and systems to track and operate net-zero buildings in the United States by 2016 (NIST 2012). The four tiers outlined by NIST for net zero building focus are: Load reduction in the building envelope, increasing equipment efficiency, on-site generation of energy, and complete building metrics. A net-zero building, is a building that, while not compromising factors such as air quality and lighting levels, creates at least the same energy as it uses in its operation. The operational database will aid in fulfilling the first, second, and fourth tiers of NIST's plan for high performance buildings in different ways. The first tier will be addressed by noting positive or negative changes in energy use when the building envelope is changed for a building type. The second tier will aid in the same manner, by noting the refits of the building's mechanical and electrical systems efficiencies.

The second function of the database is to track embodied energy. Embodied Energy is the energy in a material that was used to create the item and to construct a building. After a building is completed, the embodied energy only increases when there are additions or other work done to the building. The database tracks these changes, ensuring that KDOT will truly catalog carbon use. This is necessary since all major system work will increase the carbon totals of the buildings involved, possibly reducing the effective sustainability. This full knowledge will aid in building design, by giving more accurate comparisons of alternative systems. Full descriptions of each method of tracking embodied energy (Life Cycle Analysis, Economic-Input-Output, Process and Direct Energy Assessment Path) are addressed in the Embodied Carbon Database section.

1.5 Reasons to Move beyond LEED Certification

Currently the most used form of quantifying sustainability for buildings is the Leadership in Energy and Environmental Design (LEED) made by the United States Green Building Council (U.N. Green Building Council 2010). LEED is set on a points system, with certain prerequisites needed to achieve those points. LEED is mainly designed for the construction phase of the building. This means that LEED only fulfills aiding in the material and construction energy that is contained within the embodied energy phase. This phase, although significant in energy use, will not increase over the operational life of the building, reducing its total contribution to the lifetime energy use as time goes by. For operational energy use, there is one section: Energy & Atmosphere, shown in Table 1.2.

From this figure, only two prerequisites and 6 credits are related to operational energy in the entire checklist. Prerequisite 1 of Energy & Atmosphere involves calibrating and training personnel in mechanical equipment. Prerequisite 2 is setting the minimum energy level by utilizing ASHRAE 90.1-1999 or the more stringent local energy code. LEED is currently very relaxed regarding the system of operational energy. One of the credits requires that an energy measurement system is designed to record and maintain efficiencies of the mechanical equipment. The EIA data acquired from CBCES can be used as the base work for Credit 5, should KDOT choose to proceed with LEED certification. Although this credit is required, there is no long term method of verifying that the system is being utilized. Although LEED is a good system for new buildings, it should only be used as a starting point to increase efficiency for a completed building. This starting point can be used to make a preliminary task list that can be used to aid in designing a more efficient system for completed buildings.

TABLE 1.2
LEED Energy and Atmosphere Checklist

Energy and Atmosphere	17 Points	
Prerequisite 1	Fundamental Building Systems Commissioning	Required
Prerequisite 2	Minimum Energy Performance	Required
Prerequisite 3	Fundamental Refrigerant Management	Required
Credit 1	Optimize Energy Performance	1-10
Credit 2	On-site Renewable Energy	1-3
Credit 3	Enhanced Commissioning	1
Credit 4	Enhanced Refrigerant Management	1
Credit 5	Measurement & Verification	1
Credit 6	Green Power	1

(Source: U.S. Green Building Council 2010)

1.6 Information Added

The database for KDOT incorporates the necessary information that is needed to track operational energy use. This information is as follows: campus meter use, EIA Benchmarks, building type material list, and embodied carbon for building materials list. The campus meter use data came from the joint venture of the Phase 1 research. The collection of this data was handled by Kansas State University, which was compiled by meter number and uploaded to a joint storage site. This data was recompiled into building campuses as to give a picture of the campus energy use. The EIA benchmarks were calculated from the CBECS factors. The benchmark for each building type was set at the power used per square foot per year. These benchmarks are shown in Table 1.3 below.

TABLE 1.3
EIA Benchmarks for Building Types ((KWH/ft2)/Year)

Building Type	Description	EIA Data KWH/ft^2/year
A1	Chemical Domes: Standard, Dome, and Cone	1.75017
B4	Wash bays	6.28149
C5	Equipment Storage, 4 Bay, less than 2000 ft^2	1.3262
D6	Equipment Storage, 6 Bay, 2000 to 4000 ft^2	1.3262
E7	Equipment Storage, 10 Bay, 4000 to 6000 ft^2, Open Side	0.68323
F8	Equipment Storage, 6000 to 8000 ft^2	0.68323
G9	Equipment Storage, 8000 to 10000 ft^2, Open side	0.68323
H10	Area Office, 2000 to 4000 ft^2	67.07199
I11	Area Office 4000 to 6000 ft^2	67.07199
J12	Area Office 6000 to 8000 ft^2	67.07199
K13	Area Office 8000 to 10000 ft^2	67.07199
AA14	Storage Salt Bunker (Unused)	0.29645
AA15	Storage Salt Loader (Unused)	0.29645
L17	Sub Area 2000 to 4000 ft^2	14.33486
M18	Sub Area 4000 to 6000 ft^2 Garage portion	3.04395
N18	Sub Area 4000 to 6000 ft^2	48.56008
O19	Sub Area 6000 to 8000 ft^2 Garage portion	3.04395
P19	Sub Area 6000 to 8000 ft^2	48.56008
Q20	Sub Area 8000 to 10000 ft^2	17.91305
R21	Transmission Tower	1.80076
S22	Storage less than 2000 ft^2	0.48258
T23	Storage 2000 to 4000 ft^2	0.48258
U24	Storage 4000 to 6000 ft^2	0.38206
V25	Storage 6000 to 8000 ft^2	0.38206
W26	Storage 8000 to 10000 ft^2	0.38206
X27	Weighing Station	13.42421
Y28	Loader Storage	39.26352
Z29	Old District Shop	39.50992
2A30	New District Shop	27.12614
2B31	Laboratory less than 2000 ft^2	19.56014
2C32	Laboratory 2000 to 4000 ft^2	21.12669
2D33	Laboratory 4000 to 6000 ft^2	15.48593
2E34	Laboratory 6000 to 8000 ft^2 Garage	15.48593
2F34	Laboratory 6000 to 8000 ft^2	39.26352

2G36	Laboratory Larger than 10000 ft^2	30.1603
2H33	District Office District 3	42.93382
2I38	District Office District 1	33.54688
2J39	Construction Office District	39.26352
2K40	Salt Brine	39.26352
2L41	Radio Shop	0
2M42	District Office District 2	41.87104
2N43	District Office District 5	42.93382
2O44	District Office District 4 and 6	41.87104
2P45	Warehouse District 2	21.54109
2Q46	KHP HQ/Construction D6 D2 Annex	16.00904
2R47	KHP Office District 3 & 5	41.87104
2S48	KHP Office District 4	41.87104
2T49	HDQ Material Laboratory, Topeka	39.26352
2U50	Geology Laboratory, Topeka	39.26352
2V51	KHP District 1	41.87104
2W52	Area Office District 1	67.07199
2X53	Area Office District 1 Olathe	67.07199
2Y54	Metro Office Shop Construction	27.12614
2Z55	Conference Room/Storage (Kansas City)	19.56014
AA56	Stock Room (Unused)	0.48258
AA57	Underground Concrete Blocks (Unused)	0

(Source: Kwok et al. 2012)

This data has been used to compare the KDOT campuses to other buildings within the nation and will show how KDOT is doing compared to the national average. The embodied carbon building material list is a list of materials used by KDOT in its buildings, connected to their embodied CO_2, as shown in Table 1.4. The building type material list specifies the amount of each material used in each building type. This gives the quantity needed to accurately calculate the embodied energy and carbon. These database files will be used to make the energy simulators.

TABLE 1.4
Embodied Carbon Building Materials Totals

Reinforced Concrete	1179	kgCO2/kg	Glass	217	kgCO2/kg
Concrete	1179	kgCO2/kg	Glass Skylight	217	kgCO2/kg
Concrete Block	1179	kgCO2/kg	Glass Insul.	217	kgCO2/kg
Brick	317	kgCO2/kg	Door	14.5	kgCO2/kg
Corr. Iron	1542	kgCO2/kg	Door Reinf. Wood	14.5	kgCO2/kg
Metal	1542	kgCO2/kg	Garage Door	1542	kgCO2/kg
Fiberglass		kgCO2/kg	Door w insul. Glass	217	kgCO2/kg
Gravel	3.63	kgCO2/kg	Metal Door	1542	kgCO2/kg
Shingles		kgCO2/kg	Gravel	3.63	kgCO2/kg
Lap Siding		kgCO2/kg	Stone	317	kgCO2/kg

(Source: Kwok et al. 2012)

1.7 Energy Use Simulator

The Operational energy use simulator, online at http://www2.ku.edu/~sims/cgi-bin/KDOT/index.php is for KDOT's long-term meter tracking use. This system can show energy use by the state, district, city, county, and zip code. An example result page for Lawrence, Kansas is shown in Figure 1.4. The results shown for the database are: State Power Use by Month, [Selected Site] Vs. State Total in Power Consumption for Selected Year, [Selected Site] Vs. State Total summary Per Year, and [Selected Site] Vs. EIA Benchmark for Selected Year. The state power use by month is used to show general trends that occur in the entire state, including increase in energy use during the winter months (deicing vehicles) and summer months (air conditioning use). This aids in verifying issue sites from their counterparts. The site vs. state total per year shows how much a site or city uses compared to the whole state, aiding in finding and/or prioritizing the sites with the largest ability to reduce energy use. The site versus EIA benchmarks are used to find the sites that are running below the national average. In addition to identifying currently underperforming buildings, the database, when consistently updated with new meter data, can be used to track the performance of retrofits to see if the original energy design analysis was valid. Also, if this system expanded with more specific data, this system can be used to track energy use on new buildings that were built to the LEED standard, aiding in the Energy and Atmosphere Credit 5, Metering and Verification (U.S. Green Building Council 2010) The user manual for this database is included in Appendix A.

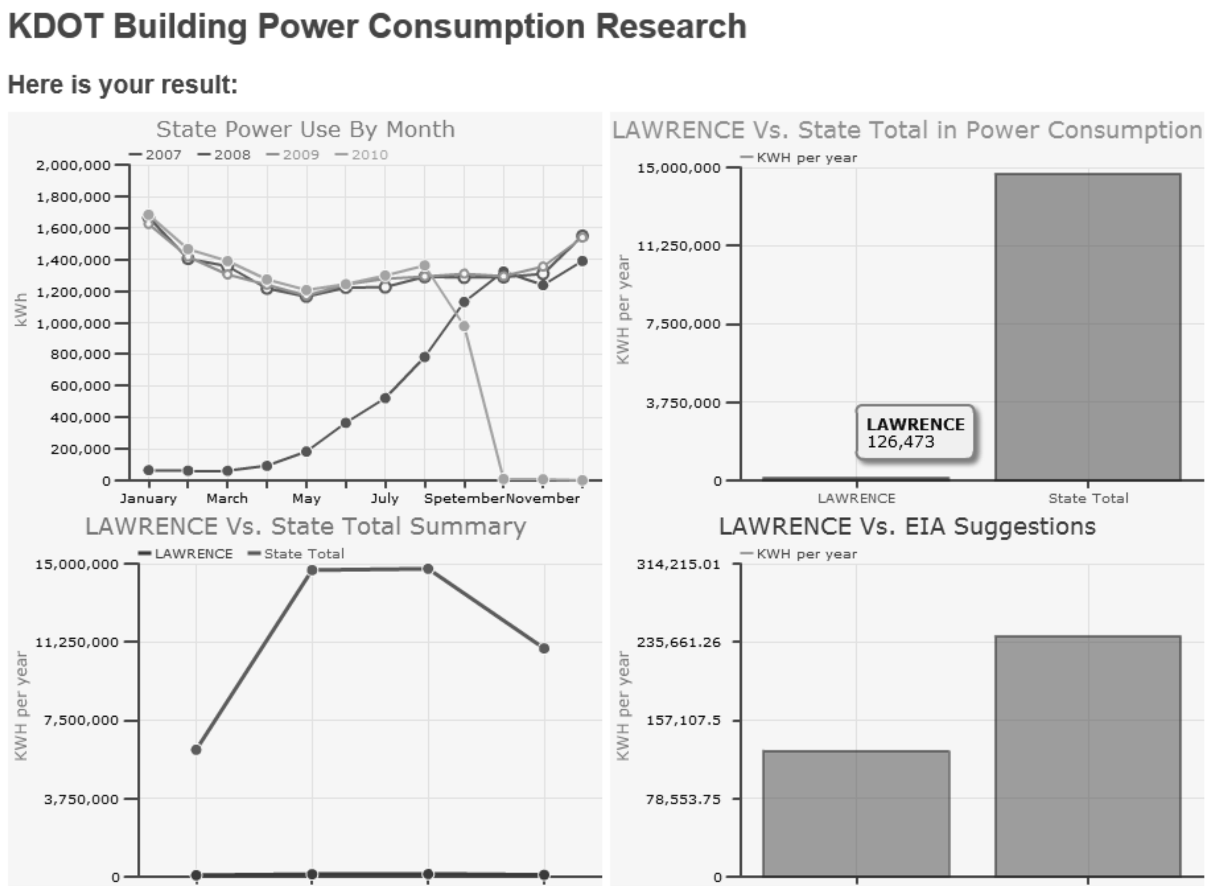


FIGURE 1.4
Operational Energy Simulator Result, Lawrence, Kansas

The positive of this database compared to other energy tracking systems, such as the Energy Star- Portfolio Manager is accuracy and the ability to update to the users true needs. While the Portfolio manager is made for small scale building management, the KDOT database is geared toward large-scale energy management which is needed for government agency in the scale of KDOT. This makes the overall system more accurate rather than repurposing a system that was not made for this amount of variables. Currently the system only goes to zip codes, for the needs that were requested by KDOT, but in the future could be tailored to different scales as required.

1.8 Embodied Carbon Simulator

As discussed in K-TRAN: KU-11-2, the four standard methods of carbon tracking: Life Cycle Analysis, Economic-Input-Output, Process and Direct Energy Assessment Path were not fully compatible with a carbon analysis in the scale that KDOT needs, therefore Enterprise Carbon Accounting (ECA) was chosen to monitor KDOT's carbon use. ECA is a carbon accounting technique that large-scale agencies use to measure and account for carbon. ECA describes a rapid, cost-effective carbon accounting process for large-scale organizations to collect, summarize and report greenhouse gas emissions and inventories (Kwok et al. 2012).

Figure 1.5 presents a partial carbon accounting flow chart showing how ECA "flows" within an organization. As seen in the figure, Transportation Carbon Accounting (TCA) details all vehicles, vehicle miles, and fuel consumption associated with an agency. These factors are dealt with in Chapters 4 and 5 of this report. The Occupational Carbon Accounting (OCA) forms the backbone of a dynamic carbon model. OCA investigates the equipment, computers, and tools that draw energy within the building as well as the embodied energy that the building consumes. Embodied energy described the indirect energy to produce the materials that are used to build the building.

Project stakeholders can improve their control of energy use and carbon emissions generated by buildings if they are able to track and understand how carbon is produced and how energy is used in each of the element shown in the above ECA. The ECA can combine all the carbon emissions and energy use from the elements to calculate the overall carbon and energy use for a building too. Both elements are useful for KDOTs overall assessment.

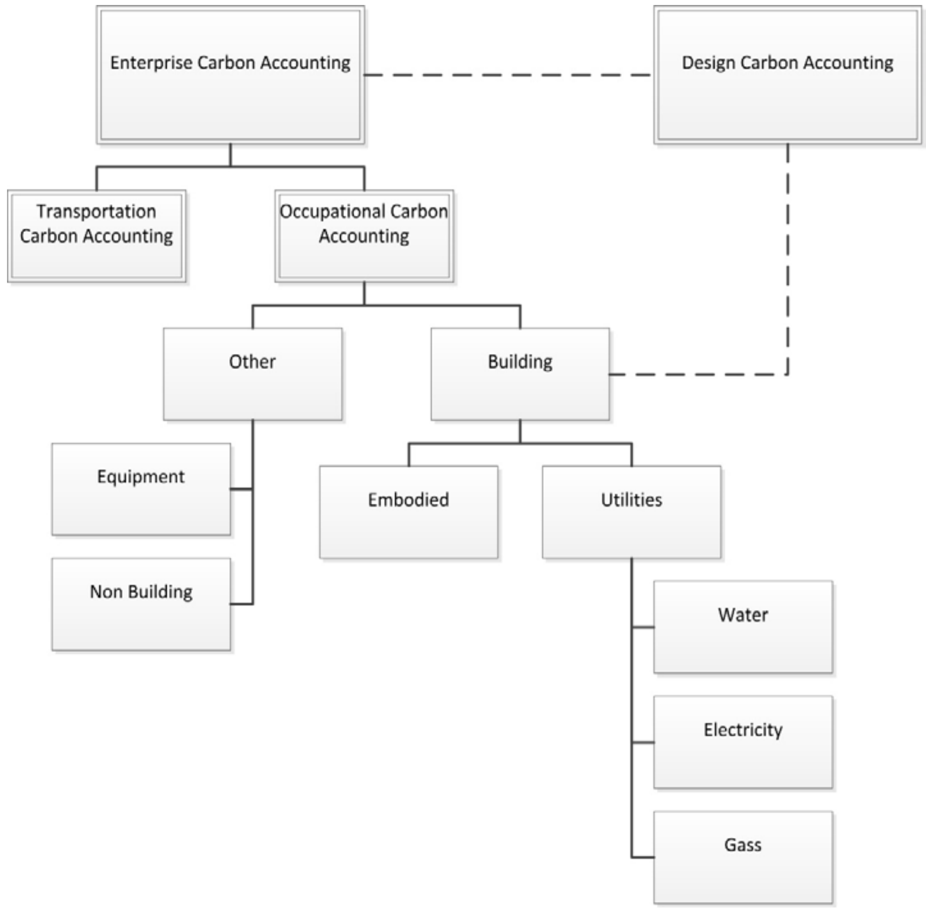


FIGURE 1.5
Enterprise Carbon Accounting

Some organizations, such as the Consortium for Research on Renewable Industrial Materials (CORRIM) claim that certain materials could be produced with less energy and generate lower amount of carbon emissions. Buchanan and Honey (1994) found that wood from Forest Stewardship Certified (FSC) forest is more environmentally friendly, uses less energy and generates less carbon to produce (and thus has lower embodied energy). Using materials with lower embodied energy and carbon helps conserve energy and reduce the release of carbon into the atmosphere, and thus create benefits to the society, economy and environment.

1.9 Cost Savings and Carbon Emissions Reduction

Koomey et al. (1998) calculated the energy, carbon, and cost savings of three models: ‘business-as-usual’ (BAU), ‘efficiency’ (EFF), and ‘high efficiency/low carbon’ (HE/LC) buildings. The three models presented strikingly different results. The efficiency model reduces energy use by 5.3% and produces 4.4% lower carbon emissions than the BAU model in 2010. This represents a saving of $18 billion in annual fuel cost. The HE/LC model generates 12% less energy use and 11% lower carbon emissions than the BAU model. This represented a saving of $33 billion in fuel cost. Even though the HE/LC model spent $13 billion on efficiency improvements and an estimated $1 to $2 billion per year in promotion and policy development costs, the saving was still greater than the EFF program (Koomey et al. 1998). This clearly highlights the cost benefits of targeting efficiency and carbon emissions at the same time.

1.10 Possible Standards for Use

For KDOT, there could be an internal standard that the agency could adopt to reduce power use; a standard above all AHJ in the state of Kansas. This would make KDOT an example for other agencies in the state on how to lower their energy use and energy costs. The standards that could be adopted by KDOT with the least interruption are: ASHRAE 90.1-2010 Energy Conservation in New Buildings Except Low-Rise Residential Buildings, LEED 2009, and ASHRAE 62.1-2010 Minimum Air Quality for Buildings. ASHRAE 90.1 as stated before is used as a standard to lower energy use in buildings when enforced by the AHJ. This standard, will aid in lowering KDOT's current lighting, HVAC, and water heating loads. Also, since this standard is currently above the state of Kansas minimum, the work can be done in phases, as KDOT deems the most necessary for the agency.

Chapter 2: Solutions

With the recommended guidelines and metrics, KDOT can go about finding the best way to increase their sustainability and reduce energy use and CO_2 emissions. One important item to note though, is no organization is likely to achieve full sustainability, and that at some point increased effort will bring about diminishing returns. This means the most effective methods must be chosen to increase the degree of sustainability. From the building operations side, the most effective way to increase KDOT's sustainability is by reducing their energy use. Within KDOT, this would be accomplished by adopting a system of consumption management. Therefore the question that would need to be asked by KDOT is, “How does our agency achieve the most sustainable practices in resource efficiency with the lowest cost?”

2.1 Embodied Energy

The most important decision for the carbon analysis process is the choice of carbon database. The values in the database directly influence the outputs of the calculator. There are several databases available for embodied carbon and energy calculation for materials. The values of the data are influenced by the LCA boundaries set for the models and the locations where the data are gathered from.

Boundaries may create greater differences than even locations can produce. While some databases only calculate the embodied energy in manufacturing a material, other databases include the manufacturing, transportation, installation, and construction energies. By expanding the given boundaries, the material values may drastically vary from one database to another.

Many organizations including the EPA and ICE have developed carbon dioxide emission equivalent databases. In this analysis, the research team utilized three reputable carbon databases, the LCEE-ASCE 2003, ICE v. 2.0, and Energy 161-2008.

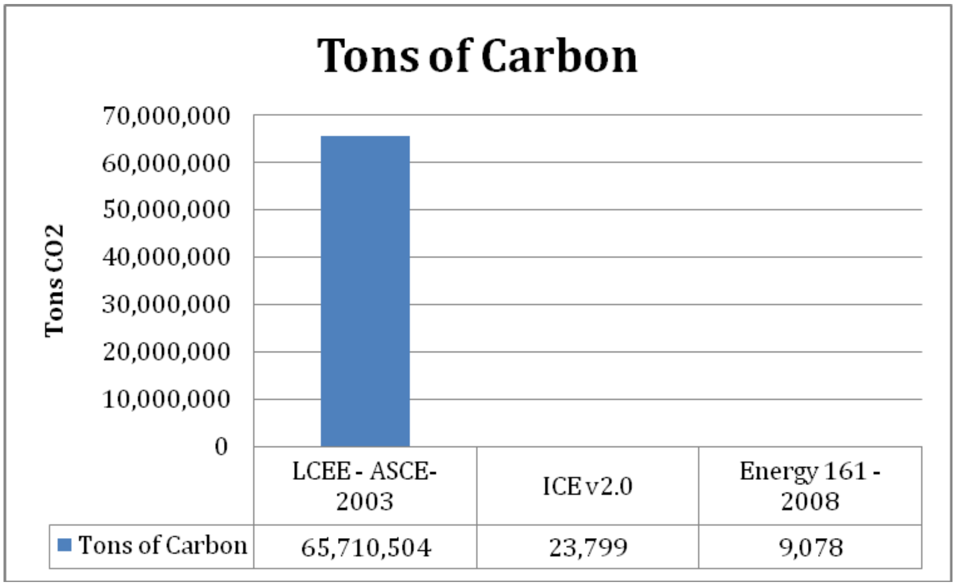


FIGURE 2.1
Total Tons of Embodied Carbon within KDOT

The three databases generate very different results as shown in the figure above. ICE and Energy 161 exclude energy use from material extraction and transportation and thus their data are lower than LCEE-ASCE-2003, which includes both. (A more complete explanation of these different calculations is located in K-TRAN: KU-11-2.) In addition to the value differences between the databases, some databases find certain materials to have exponentially greater carbon contents than others. Since the databases show roughly equivalent carbon values per material when only the material's carbon emissions are included, the difference must come from the addition of transportation, construction, and installation. Certain materials contain a higher percentage of indirect carbon than other materials.

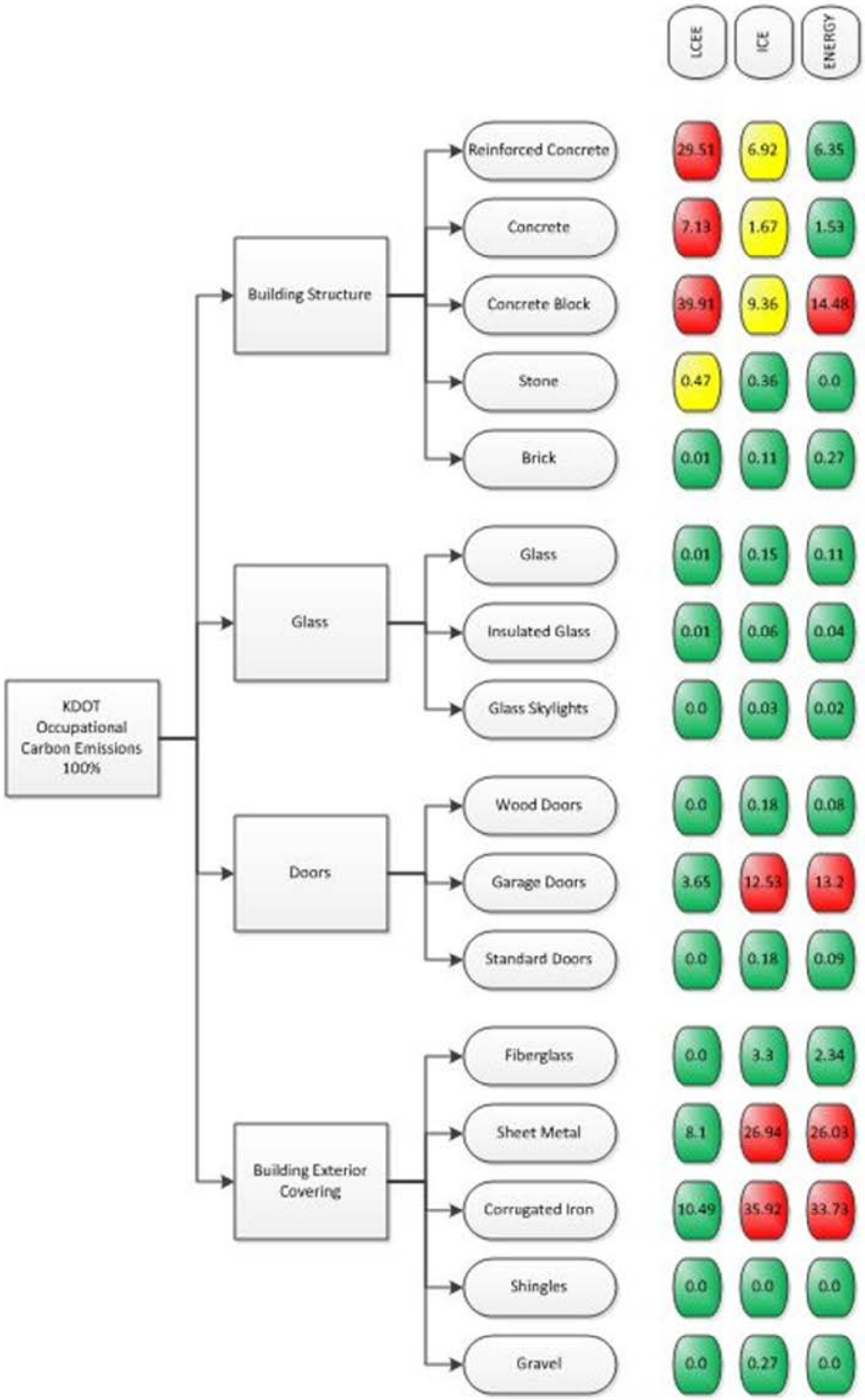
During Phase 1 of this project, all three databases were used to find embodied carbon of KDOT's building materials. These databases had different direct energy paths than each other, causing varying, but accurate, results. Figure 2.2 shows the percentage of embodied carbon per material of KDOT's buildings within the three databases. This figure, coupled with Table 1.4, can be used to aid in designing new buildings that use less embodied carbon, reducing KDOT's embodied carbon averages.

2.2 Operational Energy

One way to lower the operational energy of KDOT's buildings is to lower the needed cooling/heating load. There are a few ways to lower the load in relation to the building envelope. These are reducing infiltration/exfiltration, increasing insulation of windows and doors, and increasing insulation of walls and roof. Infiltration is the process in which unconditioned air enters the interior of the building. Exfiltration is the reverse process. Both of these are caused by air gaps in the building envelope, e.g. poor seals around windows, doors, HVAC intake/exhaust, and other protrusions from the building envelope. The best way to fix these issues is to inspect the building envelope, finding where the seals have broken down or are missing, and repair them. This repair will aid in the loss of conditioned air.

Increasing the insulation of the windows and doors is also necessary to aid in reducing energy loss. The windows for the older buildings are single pane glass, with minimal insulation value. Newer windows that are double pained, with spacing in-between both pieces of glass, have a higher R-value than single pane. Depending on the number of windows in the building, the HVAC savings would vary. The replacement of windows could be a problem if the window sizes are not the same as modern sets, increasing the cost to replace for custom sizes.

FIGURE 2.2
Embodied Carbon Contribution of KDOT Building Materials



The last way of increasing the efficiency of the building envelope is to increase the insulation in the roof and exterior walls. The insulation in the building is a larger project to complete. Most of the buildings were built in the 1950's-1960's, when the R-value (heat resistivity) were not as important to the building designers. The interior of the external walls would have to be removed, reinsulated, and rebuilt. The replacement of the insulation will also increase the embodied energy of the building. This process would be extremely time consuming for KDOT, and would be most likely too expensive. This method of reducing energy use is recommended only when the building is set for a major refurbishment.

2.3 Lighting Systems

The lighting system is one of the easier methods to lower energy use. Currently, KDOT uses T12 fluorescents for most of their lighting. A T12 lamp is a fluorescent lamp with the diameter of 1.5 inches. This lamp is one of the most inefficient forms of lighting that are currently used. In 2010, the U.S. Department of Energy (DOE) required the end of production of the ballast that is used to run T12 lamps, thus stopping the making of fixtures that use the lamps. The DOE, had also set regulations that end the production of T12 lamps in July of 2012, therefore giving the lamps a finite lifespan. This makes it necessary for KDOT to upgrade its lighting system to using T8 (Fluorescent), T5 (Fluorescent), or LED (Light-Emitting Diode). With this upgrade, KDOT should adopt the current recommend task lighting levels that are prescribed by the Illumination Engineering Society of North America (IES), shown in Table 2.1. These recommended lighting levels will reduce the chance of supplying an excessive amount of light for a given task. This simple design consideration will lower the energy used when the lights are on.

TABLE 2.1
IES Task Lighting Levels

Office Space	Area Nominal Illumination Level in Lumens/Square Meter (lux)
Normal work station space, open or closed offices	500
Conference Rooms	300
Training Rooms	500
Corridors	200
Auditoria	150-200
Public Areas	
Entrance Lobbies, Atria	200
Elevator Lobbies, Public Corridors	200
Ped. Tunnels and Bridges	200
Stairwells	200
Support Spaces	
Restrooms	200
Locker Rooms	200
Storage Rooms, Janitors' Closets	200
Electrical Rooms, Generator Rooms	200
Mechanical Rooms	200
Communications Rooms	200
Maintenance Shops	200
Loading Docks	200
Trash Rooms	200
Specialty Areas	
Dining Areas	150-200
Structured Parking, General Space	50
Structured Parking, Intersections	100
Structured Parking, Entrances	500

(Source: U.S. General Services Administration 2012)

The T8 fluorescent light is a small diameter fluorescent, 1 inch, and is now used as the main lamp for office and low bay lighting systems. On average, T8 fixtures use 33% less energy than their T12 counterparts (Illuminating Engineering Society 2009). The average lamp life of a T8 is double that of a T12, around 24,000 hours compared to 12,000 hours. The lamps also use the newer electronic ballast, which holds many advantages compared to the magnetic ballast of the T12 lamps. The electronic ballast can power more lamps, can be made dimmable, are made to be integrated into advanced lighting control systems, and are more energy efficient. The T8 system is standard enough to be reasonable in cost and is a viable option for KDOT's use. The T5 lamps have most of the same advantages in a smaller package (5/8"), are also used in offices, and use the electronic ballast. The average lamp life is smaller, 20,000 hours. This lamp is also a valid contender for a lighting upgrade.

LEDs are currently the ‘new thing’ in lamps. The LED, or Light-Emitting Diode, is a lighting system that has an average lamp life of over 100,000 hours. The LED can, depending on the quality, use on average 66% less energy than fluorescents in office applications. Also, LED systems emit very little heat, lowering the cooling load to the HVAC system. The lamps are also dimmable, making them useful with new daylight capturing methods. To completely remove all fixtures and replace them with LED fixtures may be cost prohibitive, but this does provide an option for new or completely refurbished offices. There are also replacement lamps for fluorescents fixtures that use LEDs instead of the original lamps, meaning KDOT can upgrade the lighting to LEDs from fluorescents by bypassing the ballast in the fixture and installing the new lamps. These lamps compare in light intensity, and last over eight times the amount of KDOT’s current T12 lamps. The power savings are also greater, such that a comparable 40 watt T8 lamp would equal an 8 watt LED replacement lamp. Since the ballast is bypassed, any LED replacement lamp could be used as long as the lamp had the same connectors and length of the former fluorescent lamp. The one problem is cost. One LED lamp can cost $40-$60, compared to a T8’s cost of $5-10. When the cost is coupled with the life of the lamp (4.1 times longer for a T8), and the energy savings (8 watts from T8 40 watts), and the current cost of energy of $0.0807 per KWH, the potential savings can be calculated from the following equation: (Institute for Energy Research 2010).

$$S = \frac{L_{LED}}{L_f} * [C_f + (R_{ave} * L_f * \frac{P_f}{1000})] - [C_{LED} + (R_{ave} * L_{LED} * \frac{P_{LED}}{1000})]$$

Where:
S = Savings (Dollars)
L_f = Life of Lamp, Fluorescents (Hours)
L_{LED} = Life of Lamp, LED (Hours)
C_f = Cost of Fluorescent Lamp (Dollars)
C_{LED} = Cost of LED Lamp (Dollars)
P_f = Power of Fluorescent Lamp (Watts)
P_{LED} = Power of LED Lamp (Watts)
R_{ave} = Average cost of electricity per KHW (Dollars)

Equation 2.1 Replacement Lighting Savings

With this formula, using the highest cost of LEDs ($60, 18 watts, 100,000 hours) and the lowest cost of fluorescents (T8 $5, 40 watts, 24,000 hours), KDOT will save $132 per LED lamp. This is assuming KDOT uses the most inefficient LED lamp. If KDOT uses more efficient lamps, the savings increase to around $213 per LED lamp. This calculation does not include the savings from not needing to replace the fixture, or the cost of work hours needed to bypass the ballast on all compatible lamps. This method can be done over months, reducing the total fixtures needing T12 lamps, while KDOT's supply of T12s reduces. This lighting system is the best long term savings for money between the three systems.

Another way to increase the savings for lighting is to use occupancy and daylight sensors. The occupancy sensors detect if a person is in an area, and after a certain amount of time, shut off the lights if they are left on. If ASHRAE 90.1 is enforced by KDOT, occupancy sensors will be required for most areas of the campuses. The occupancy sensors will reduce the wasted light from rooms such as meeting areas, break rooms and restrooms when there are gaps between use of the room, making savings more substantial. The daylight sensors are used to maintain a set lighting intensity for a room/area. These controls will power the lights to only what is needed for the total lighting level set, saving power during the day. Since KDOT's main hours are during the daytime, this could aid in large energy savings.

2.4 HVAC Systems

HVAC systems take up the majority of total energy use by a building. This means that any increase of efficiency can mean significant savings. With this in mind, all variables need to be considered that affect the cost feasibility of replacing an HVAC system. The main issue is that HVAC systems contain large, expensive equipment that are only replaced when the system has reached the end of life. Without replacing the larger systems, there are a few options that can be implemented, such as new control systems, increased use of insulation, and filter replacement.

A new control system is more achievable in an HVAC system without a large refit of the building. One of the controls is to set programmable timers for the building, reducing the cooling load during reduced operational hours and shutting down during no occupancy conditions. These systems can also be used to remove the need for HVAC systems to introduce unneeded outside, unconditioned air into the building by monitoring CO_2 levels. These sensors only introduce the unconditioned air when deemed necessary, reducing the overall cooling and heating load to the building, thus saving energy.

Although fully removing an HVAC system is costly, care can be taken in the design of a new HVAC system when the current one has approached end of life or when necessary changes are needed in relation to building use. These design considerations could be as complex as changing the entire system layout and operation, or simply being mindful of sustainable alternatives within the current system. Although a majority of the equipment is similar, there are different delivery systems which greatly change the efficiency of the systems greatly. These delivery systems are Constant Air Volume, Variable Air Volume, and Demand Control Ventilation.

The most common HVAC design when most of KDOT’s buildings were originally built were Constant Air Volume systems (CAV). CAV systems are where the delivery of conditioned air to a building is done by changing the temperature of conditioned air delivered while still maintaining the same volumetric flowrate at all times. This system uses a large amount of energy from constantly reheating or recooling the air to what is currently needed. The other issue is that this system only runs the building on one zone, giving the same temperature of air to the whole building, overheating or overcooling different rooms. This system is still used when upfront costs need to be low, or for very small buildings only needing one zone and a lower thermal comfort.

An alternative approach, Variable Air Volume (VAV) has been popular in the last 30 years. A VAV system is where a main system conditions air to a certain temperature (~55 ^{o}F) which is then sent to a small automatic damper system that heats the air to what is needed in the zone. This system, while also controlling the delivered air temperature like a CAV, also controls the flowrate of the air to the zone. This higher level of control means that the system uses less overall energy by only using smaller equipment to reheat air and controlling the amount of air needed. This system provides better comfort, with up to 33% energy savings over a similar CAV system. This is due to lower loads on equipment such as boilers and chillers during operational hours.

This system is the most popular design in HVAC currently, and with HVAC system lifespans around 20 years, it is safe to assume most, if not all of KDOT's HVAC systems have been updated to this design for offices. However, there are ways of increasing efficiency of VAV systems without full replacement of all the equipment. Some of the easiest ways to reduce energy use are to insulate the pipes connected to the chillers, boilers, cooling towers, and air handling units (AHU). The other significant place to insulate is on the supply and return ductwork. This insulation reduces energy transfer between the conditioned air and the unoccupied areas of the building, therefore only dealing with occupied area loads. A DCV is a delivery system that in the core is a VAV, but contains economizers and CO_2 sensors. This makes the DCV even more efficient than the VAV system, but also offers a method to upgrade existing VAV systems to a basic DCV system. Currently, the savings incurred in different areas of the country show the DCV system saving anywhere between $0.05 to over $1 per square foot with an average payback of three years (Federal Energy Management Program 2004). This method of upgrade would be quicker to implement than other HVAC changes.

When new HVAC equipment is specified for construction or replacement, the sustainability of the equipment should be considered during the design process. Replacements for larger systems should take into account issues such as: equipment efficiency, effectiveness of equipment with current system, what quantity of chemicals are used, what is the carbon output of the fuel used, and what energy saving controls are offered. Each of these design considerations should be exceeded by the replacement equipment as much as possible from the existing systems. There are also some pieces of equipment that can be installed without replacing the major equipment, such as economizers, that require only extra modification to the control system. An economizer is a system that, under the right conditions, will bypass certain systems to reduce energy. With HVAC there are two types of economizers, air and water side. Air side economizers detect when the conditioning of outside air is more efficient than reconditioning the interior air, to the point where, if the outside air is within a certain tolerance, the conditioning system will shut down altogether. This condition has only the fans in the HVAC system running, saving energy from the rest of the equipment. A water side economizer is where the chiller is bypassed if the water inside the cooling tower is within a certain range.

2.5 Water Systems

For many KDOT sites, one way to reduce energy consumption is to replace the water heaters with demand (tankless) water heaters or solar thermal systems. These heaters only use energy when hot water is needed. These systems are only efficient in areas with low hot water use, under 41 gallons (U.S. Department of Energy 2011a; b). These savings could be up to 33% compared to a similar tank type water heater. A solar thermal system contains a solar collector and a storage tank. The solar thermal system most used for heating water is a dual type system, where the heated fluid, containing glycol, runs thru the collector and a set of heating coils within a tankless heat exchanger or hot water storage tank for future use. Either system need a very small pump to keep the glycol mixture moving as to not cause damage to the solar collector, but the energy use is negligible. To increase the efficiency even more, the tank/heat exchanger should be insulated, reducing heat loss. The negative of the solar thermal system is that it is not as effective during cloudy days, thus the tank solar thermal system is recommended to maintain reliability. Both systems remove the need for natural gas lines to heat lower hot water use buildings.

2.6 New Sources of Energy Production

Another way to reduce KDOT's energy use is to have KDOT produce its own energy in-house. Building internal energy production systems should only be done when all other systems have been fully optimized. Sources for in-house energy can include photovoltaic (PV) or wind systems. Both systems should be tied into the electrical grid, with net meters. With these net meters, KDOT can get credits (not money) from the utilities, lowering utility costs. Also, there are grants from the United States Department of Energy to build such systems, possibly paying the cost of construction and/or maintenance expenses. The PV system, commonly referred to as solar, tends to have a 20-30 year payback. The issue in Kansas is the severe weather that could damage the PV systems. There is insurance in this event but it needs to be considered in the payback and total cost of using this system. The other issue is the amount of land used by a PV system, since each panel cannot obscure another panel without reducing the efficiency of the system. By contrast, wind turbines can be built in small scale, offsetting the majority of the cost of the site, and using a small land footprint. These wind turbines are quite useful in the state because of the steady, medium velocity wind that is present in Kansas as shown in Figure 2.3. This system is also easier to install into a net grid system than a PV system which needs DC inverters and other equipment. The turbines can be pre-built, to be tied into the electrical grid, saving some development cost. If the systems are tied into the electrical grid, development of the system would need to done in conjunction with the local power distributer and the AHJ. Certain building permits would be needed as well.

Wind- Average Wind Speed- (MPH)

DATA THROUGH 2002	YRS	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
CONCORDIA, KS	40	11.7	12.1	13.4	13.8	12.1	11.7	11.3	10.9	11.2	11.6	11.8	11.5	11.9
DODGE CITY, KS	60	13.5	13.9	15.5	15.5	14.6	14.0	13.1	12.5	13.5	13.5	13.7	13.4	13.9
GOODLAND, KS	54	12.4	12.4	14.0	14.4	13.5	12.7	11.9	11.5	12.0	11.9	11.9	11.9	12.5
TOPEKA, KS	53	9.7	10.2	11.5	11.7	10.2	9.4	8.4	8.0	8.5	9.0	9.7	9.5	9.6
WICHITA, KS	49	12.0	12.5	13.8	14.0	12.3	12.2	11.3	11.1	11.6	11.9	12.1	11.7	12.2

(Source: National Climatic Data Center 2008)

FIGURE 2.3
Kansas Average Wind Speed Data

The problem with wind turbines is that many of the generators have a start up speed of 7.5 mph. This means the turbine needs a wind speed of 7.5 mph to start up the system when the blades are not moving. Depending on the height of the turbine (< 50 feet), this might cause a problems in certain areas of Kansas where the average wind speed is too low. This system should only be used sparingly, after a proper survey has been conducted for the site.

2.7 Habit Changes

One of the least expensive methods to reduce energy consumption is to promote habit changes. The KDOT administration can implement policy changes that would change how the employees utilize energy in day-to-day operations. These habit changes are numerous. Some simple ones are to turn off lights when employees leave a room, set thermostats lower in the winter and higher in the summer, open shades in areas for natural light, turn off computers at the end of the day, and keep windows closed when the HVAC system is active. Other complex methods are to shut down boilers in the late spring to early fall and shut down the HVAC system over weekends and other periods of no worker activity. These will reduce unused energy to a minimum. To reinforce these habits, KDOT could create a contest where sites compete to reduce their energy use, and have the site with the largest percent reduction wins a prize. Other methods of adoption can be utilized, but should always be portrayed in a positive way.

Chapter 3: Recommendations

With these solutions presented, the question becomes to decide which methods are best for KDOT. Multiple factors must be considered in this decision, primarily energy savings, replacement costs, payback time, and future replacement time. These variables are compared for different options in Table 3.1. The factors listed here are only general baselines, since a more accurate analysis would have to be done for each system on a case by case basis with the most current information. The cost of the system is based on the expense of the system compared to the potential savings. A lower cost designation implies that the system has a higher payback ratio (potential savings over equipment lifespan) compared to the other alternatives. A payback time equaling or exceeding the equipment lifetime, is designated a ‘high’ payback, with shorter payback ratios being shown as ‘low.’ The Energy savings is based upon the potential reduction of energy from the current baseline. This is an estimated average for systems such as HVAC since different systems for the same building type could be decades apart based upon maintenance issues. Future replacement is based on the lifespan of the system with low being five year or less, medium from six to ten years, and long being 11 or more years.

After evaluation using the criteria in Table 3.1, a list of sustainability projects to complete can be compiled. These projects are listed below from the easiest to implement in relation to cost and work to the most complex:

1. Habit Changes
2. LED fluorescent replacements (T8, T5 replacement alternative)
3. VAV to DCV retrofit
4. Lower Embodied Energy Materials
5. Tankless water heater replacement
6. HVAC Upgrade
7. Energy Generation (Wind, PV, Solar Hot Water)

These systems are just a short list of solutions to KDOT’s energy use. It's very important to remember that these changes will take some time for these paybacks to be noticeable. While the solutions presented may not have instant results in cost effectiveness, the long-term benefits of saving money and decreasing the detrimental effects on the environment greatly outweigh any of the short-term benefits of not spending the money and effort to decrease the carbon emissions that KDOT produce. Just implementing habit changes into employee policy can save on energy and money if they make the employees more conscious of what one uses and wastes in a day. For the times that someone forgets to turn off a light when leaving work it would be much better to have a motion sensor pick up that no one is in the office and switch off lights rather than waste money paying for that light being on all night. The changes implemented could be large or small but the bottom line of the situation is that money is saved and energy use is decreased.

TABLE 3.1
Solution Feasibility Table

Solution	Cost	Payback Time	Energy Savings	Future Replacement?	Notes
Lower Embodied Energy Materials	Medium	High	Low	None	To reduce embodied carbon
T8,T5 Replacement	Medium	Low-Mid	Low-Mid	Ballast, Long Lamps, Low	Cost is of fixture replacement
LED lamps (Fluorescent replacement)	Low	Low	High	Lamp, Medium	Lamp cost only, slow phase-out
HVAC equipment replacement	High	Mid-High	Medium	Long	End of life replacement
VAV to DCV	Low	Low	Mid-High	Medium	
Hot water (Tankless)	Low-Mid	Medium	Medium	Medium	Low HW use buildings only
Hot water (solar)	Mid-High	High	Medium	Medium	
Wind Turbine	Mid-High	High	Mid-High	Long	Assuming design at 50-80% of building energy use
Photovoltaic	High	High	Low-Mid	Long	Assuming design at 50-80% of building energy use
Habit changes	Low	Low	Mid-High	None	

Chapter 4: Evaluation of KDOT's Vehicle Fleet's CO_2 Emissions and Possible Energy Reductions

4.1 Background

Energy conservation through increased efficiencies, lower demand for energy from behavioral changes in users, and increased use of renewable energies is becoming more widespread 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 some level of unfavorable emissions, both greenhouse gases and other pollutants which can lead to adverse health effects or a decline in environmental quality. Historically, CO_2 has not been a major air pollution concern due to its low toxicity. Recent developments, based on CO_2's links to global warming and climate change have shifted the concern surrounding CO_2 emissions, however. Following *Massachusetts vs. Environmental Protection Agency,* in which the U.S. Supreme Court found that EPA has authority to regulate greenhouse gas tailpipe emissions under the Clean Air Act, EPA issued findings addressing the impacts of greenhouse gases and CO_2 emissions from new motor vehicles (U.S. EPA 2009). Future regulation of CO_2 emissions from both stationary and mobile sources to reduce overall levels of greenhouse gas emissions is therefore very likely.

Greenhouse gases (GHGs) such as CO_2 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. The full relationship between greenhouse gas emissions and environmental impacts is quite complex, and beyond the scope of this report. For our purposes, it is expected that these gases will be increasingly regulated in the near future, requiring accounting for their emissions.

Carbon dioxide is released from both natural and anthropogenic sources into the atmosphere. 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. The EPA estimates that transportation sources accounted for approximately 30% of all CO_2 emissions in 2010, with approximately two thirds resulting from gasoline combustion and the remainder from diesel and jet fuels (U.S. EPA 2012a). Since the 2009 endangerment findings described above, EPA has made several moves towards regulation of mobile CO_2 emissions. In 2010, EPA and the National Highway Traffic Safety Administration (NHTSA) established standards for greenhouse gas emissions and corporate average fuel economy for light duty vehicles for the 2012-2016 model years. This rulemaking was extended in 2012 to cover the 2017-2025 model years. (Full regulations and descriptions are available from the U.S. EPA Office of Transportation & Air Quality at http://epa.gov/otaq/climate/regs-light-duty.htm (U.S. EPA 2012b)) While off-road vehicles are currently not subject to similar regulations, this may change in upcoming years. In addition, EPA's Renewable Fuel Standards program mandates the blending of renewable fuels (including biofuels) with transportation fuels at increasing levels through 2022 in order to reduce net CO_2 emissions (U.S. EPA 2012c).

KDOT employs a large fleet of vehicles throughout the state to achieve the tasks assigned to them. As part of the Phase 1 project preceding this report, a database of fuel consumption by the KDOT vehicle fleet was compiled from existing records of all vehicles owned and operated by KDOT from fiscal years 2005-2011 (Kwok et al. 2012). For this vehicle fleet, fuel use, CO_2 emissions and energy costs are roughly interchangeable, as fuel combustion will be the major source of CO_2 emissions and the major operational expense. This database therefore has significant potential both for analysis of existing KDOT fuel use patterns and for recommendations to lower KDOT's fuel use (and therefore costs) and overall CO_2 footprint.

The motivation to reduce spending is obvious, but the benefits to KDOT of reducing CO_2 may not be so apparent. Knowing how much CO_2 they are producing and how it compares to the EPA's current and proposed standards is a crucial first step in evaluating subsequent steps for KDOT to limit the impacts of any new regulations. This project will provide KDOT with this baseline CO_2 production. In addition, increased emphasis on CO_2 is already leading to expanded pressure for more use of renewable fuels, including biofuels. Since biofuels come from plant mass and plants use atmospheric CO_2 in their metabolism and life cycle, substitution of these fuels for petroleum based fuels has the potential to reduce net CO_2 emissions without affecting the amount of fuel consumed. While there are not significant monetary savings available from biofuel use under current conditions, additional information on the properties and requirements of these fuels is necessary if they are to play a larger role in KDOT operations.

In Phase 2 of this project, we expanded on and revised the data compiled from Phase 1 on KDOT fuel use and vehicles fleet activities. 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 that was developed into a fully usable database for Phase 2, allowing KDOT to use this system to track future fuel consumption and CO_2 emissions. The existing database records were also analyzed to develop strategies to minimize KDOT fuel consumption from the current vehicle fleet. Finally, we have compiled a brief primer on the properties, use and storage of biodiesel and biodiesel blends. This primer addresses the renewable fuel most commonly used by KDOT (both now and in the immediate future) and provides suggestions for its increased use in KDOT operations.

4.2 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, KDOT 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 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 B.

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 B.

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 following screenshots show what has just been described.

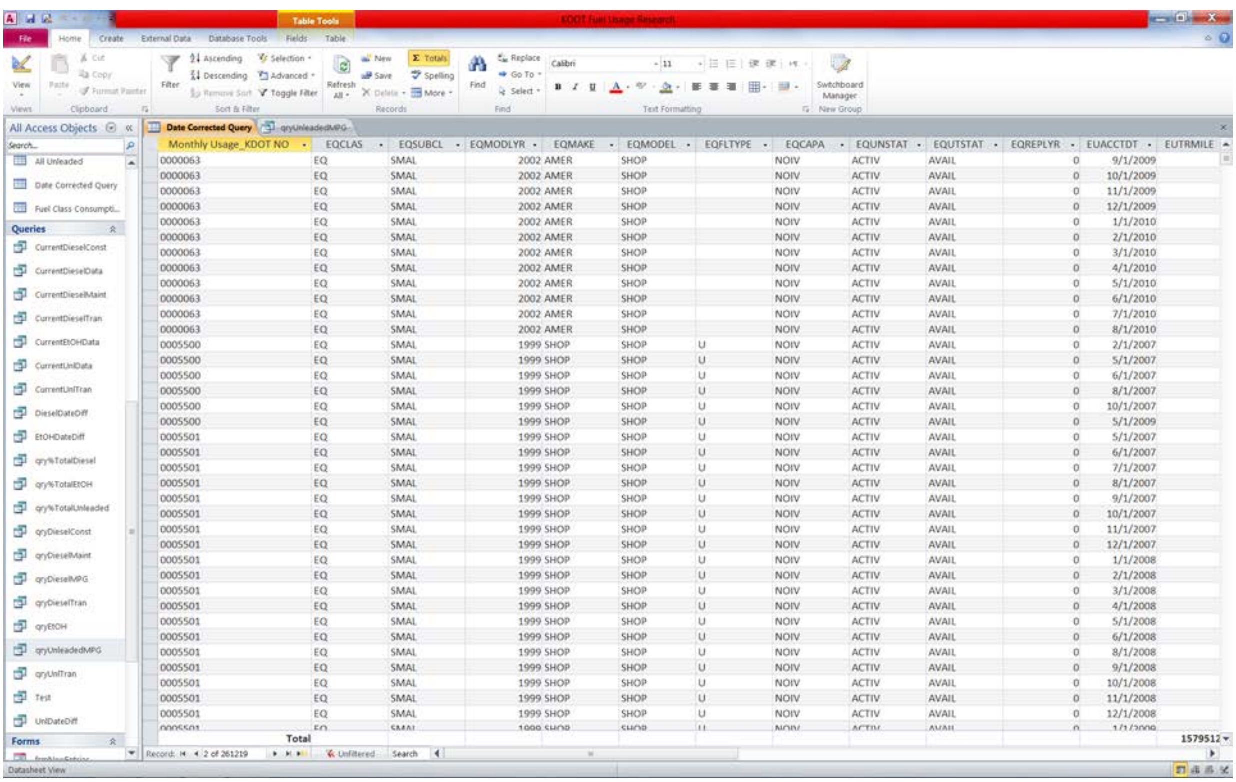
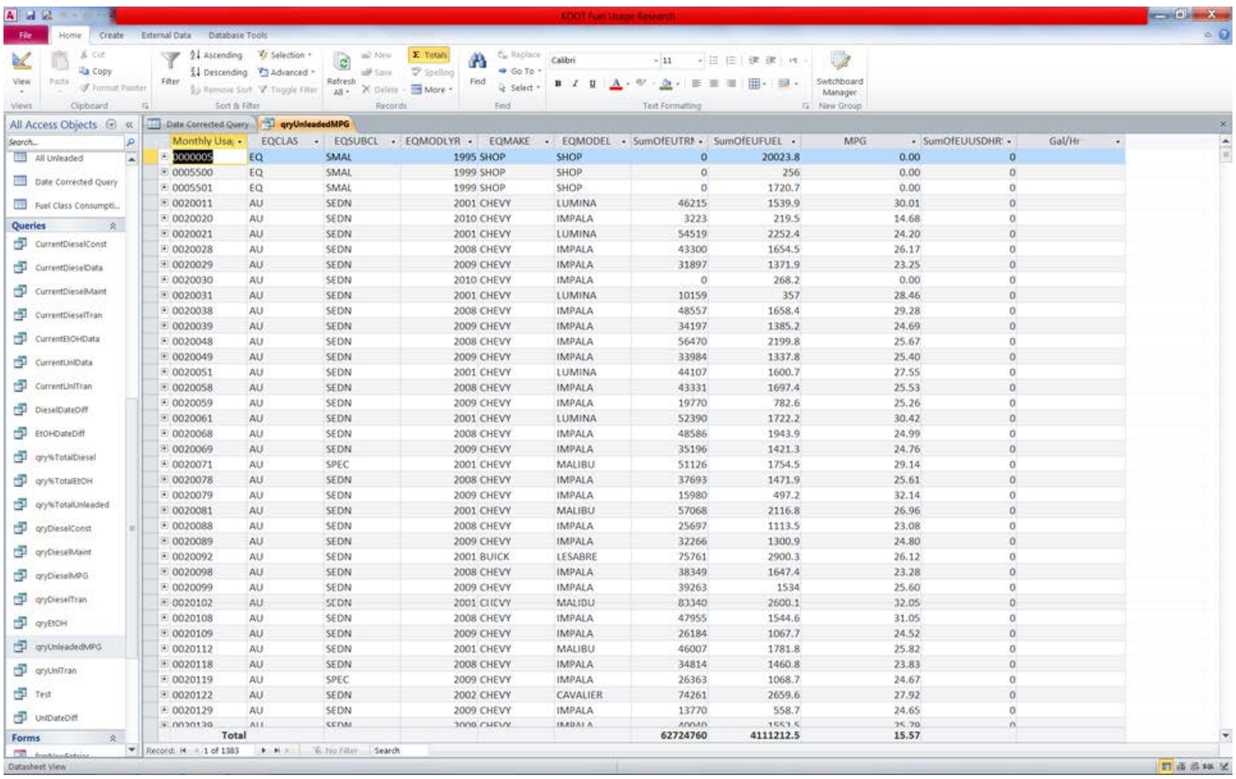


FIGURE 4.1
Screenshot from the Master Table in Fuel Records Database, “Query Date Correction”

The screenshot in Figure 4.1 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.



Note: This query groups records by the internal vehicle ID with total values for miles traveled, hours used, and fuel consumed for each vehicle ID.

FIGURE 4.2
Screenshot from the Query, "qryUnleadedMPG" in the Fuel Records Database

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 in Figure 4.3 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.

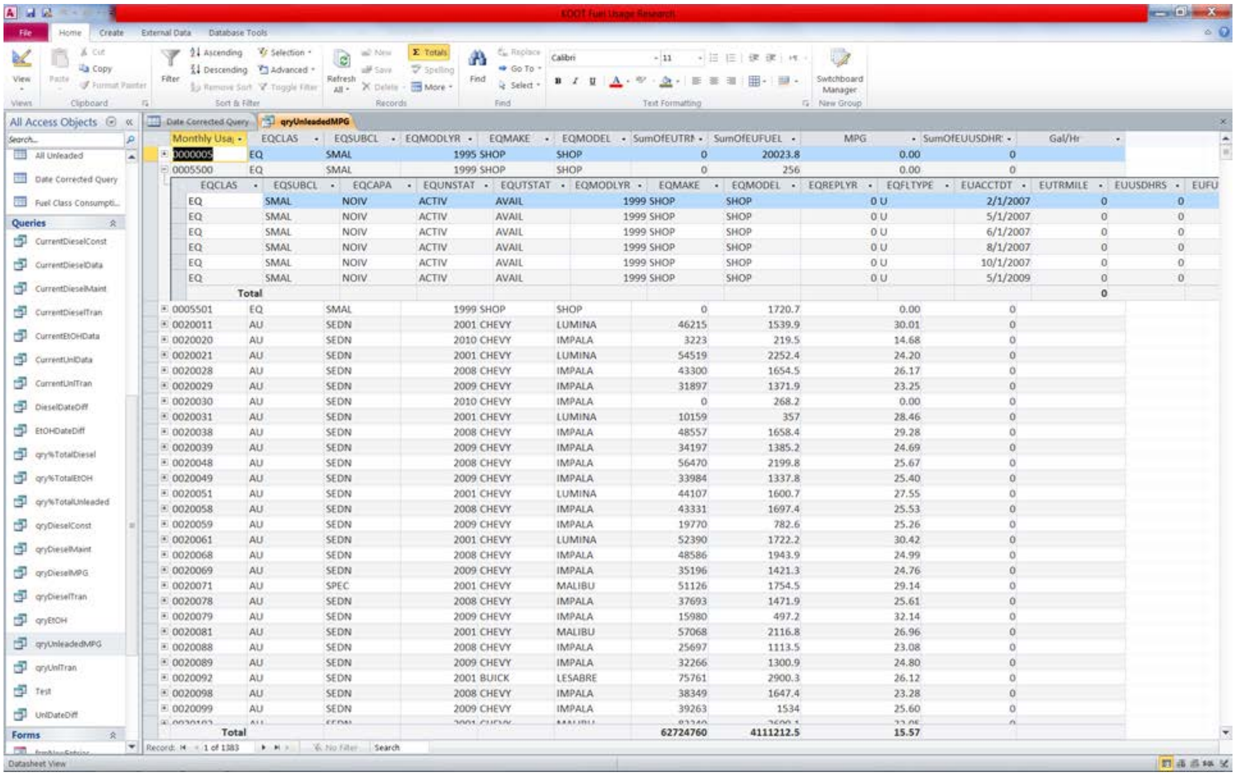


FIGURE 4.3
Screenshot from the Query, "qryUnleadedMPG" in the Fuel Records Database with the Subdatasheet Expanded to Show all Individual Records from the Master Table for a Particular Vehicle ID, in this Case 0005500

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 B.

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 (GPH) 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.

4.3 KDOT Fuel Use

As described in more detail in the Phase 1 report, KDOT's fuel purchases consist of a mixture of diesel and gasoline fuels in approximately a 2:1 ratio (Kwok et al., 2012). These ratios are not, however, represented in the actual fuel use database, as a substantial portion of the gasoline purchased by KDOT is instead used by the Kansas Highway Patrol. Records provided for fiscal year 2011 show KDOT vehicles used only about 60.5% of the total gasoline pumped at their filling stations. This is consistent with the analysis of fiscal 2006-2010 data, which showed that KDOT gasoline use ranged from 56-70% of the purchased fuel numbers for the same year. Unlike purchasing records, the fuel usage records on which the Microsoft Access database is built do not distinguish between pure gasoline and E10, nor between pure diesel and B5 fuels, so diesel and unleaded numbers here refer to all fuels of each type.

Based on these results (Figure 4.4), actual yearly KDOT fuel use is around 80% diesel fuels (including biodiesel blends of up to 5%) and 20% gasoline fuels (including 10% ethanol blends). Within the individual vehicles listed in the database itself, 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 category for ethanol fuels, is for flex-fuel vehicles. These vehicles can be filled with either E85 (85% ethanol) or with standard gasoline. Therefore, a record may show ten gallons of fuel for a flex fuel vehicle, but not whether that fuel was actually E85 or standard unleaded. In our database, this is all recorded as E85 fuel. The total amount of fuel in these vehicles, about 131,000 gallons annually, is very small when compared to the 4 million and 16 million gallons of unleaded and diesel, respectively. Thus, any discrepancies in this category have a minimal effect on overall calculations.

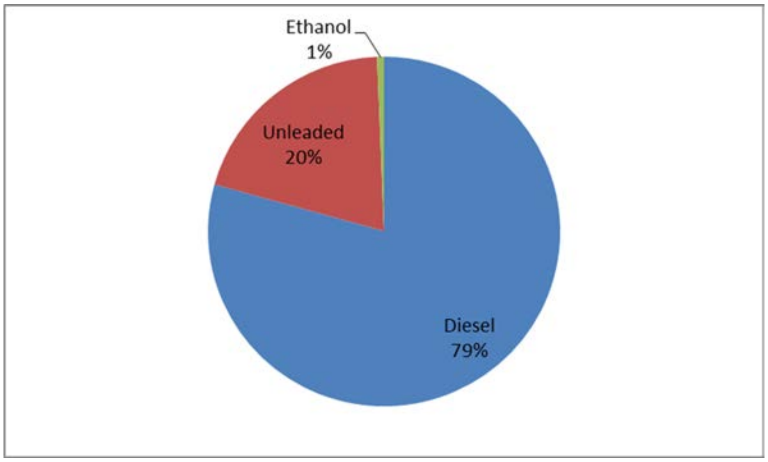


FIGURE 4.4
Relative Fuel Consumption by Fuel Type

4.4 Fuel Use Trends

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.

The totals of miles traveled, hours used, and fuel consumed are calculated and shown at the bottom of the column in each database table. Looking at the total quantity of each type of fuel used shows that diesel represents 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 (E85) does not show much promise for savings due to its relatively small use in KDOT's fleet.

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 4.1
Fraction of Fuel Use by Equipment Class

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 (Table 4.2), 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.

TABLE 4.2
Breakdown of Fuel Consumption by End-Use

Use	% of Total	MPG	GPH
Diesel			
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	-

Note: Numbers in parentheses show calculations neglecting dump truck consumption.

After 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, based on published EPA conversion values (U.S. EPA 2011). Figure 4.5 shows the breakdown of relative CO_2 production by fuel type. If this figure is compared to Figure 4.4, 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).

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 4.2.

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 the transportation category because there are no records for hours used for those vehicles.

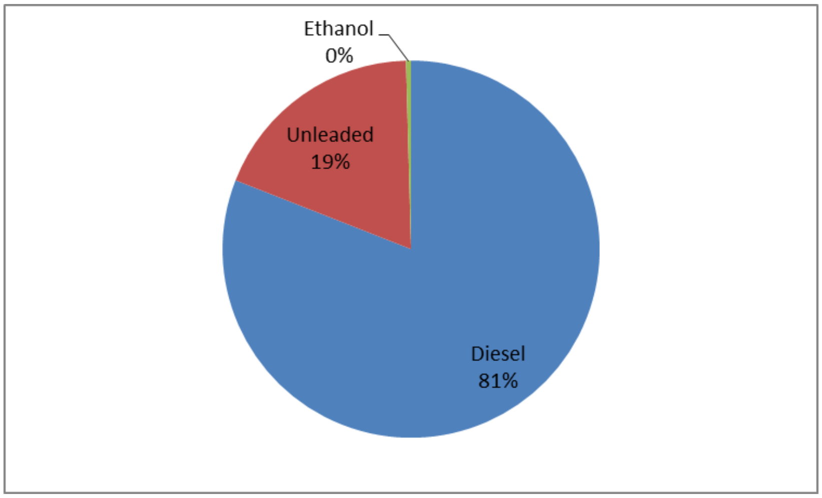


FIGURE 4.5
Break Down of CO_2 Produced by Each Fuel Type

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.

4.5 CO_2 Emissions Trends

After an upward trend for the first three years, the overall CO_2 emissions decreased substantially and then plateaued for the remaining three years of the study. Unleaded fuel use, by contrast, declined each year during the study period. The decreasing trend is likely attributable to efforts by KDOT staff to drive more economically, with a noticeable drop in FY 2008. 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. 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. Figures 4.5-4.7 illustrate these trends. Note that the higher diesel fuel use means that the overall CO_2 trends closely parallel those for diesel fuel.

Additional analyses 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 year (Figures 4.8-4.10) showed very similar results to CO_2 emissions, as did miles traveled per year (Figures 4.11-4.14). 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.

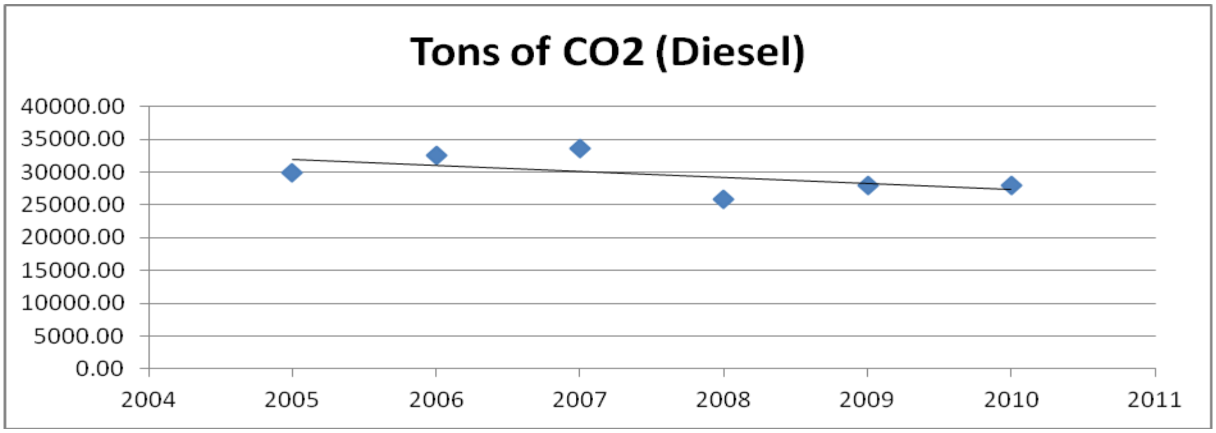


FIGURE 4.6
Tons of CO_2 Produced by Diesel Fuel Consumption in Each Year

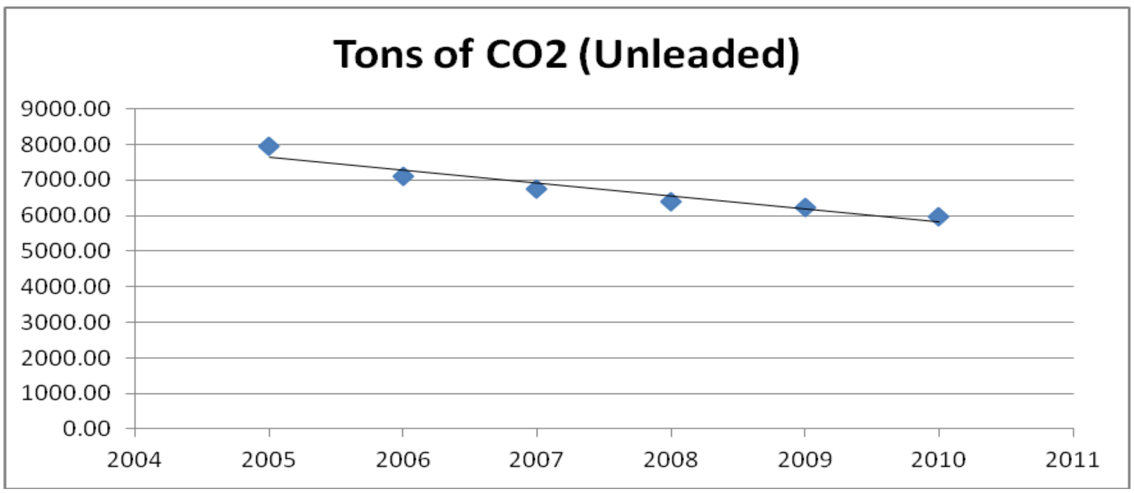


FIGURE 4.7
Tons of CO_2 Produced by Unleaded Fuel Consumption in Each Year

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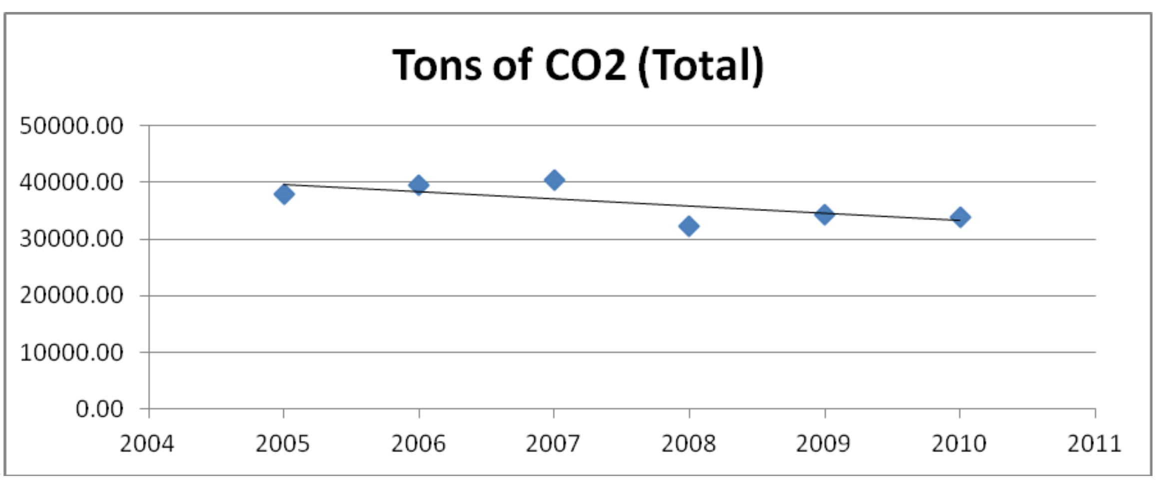


FIGURE 4.8
Tons of CO_2 Produced by Total Fuel Consumption for Each Year

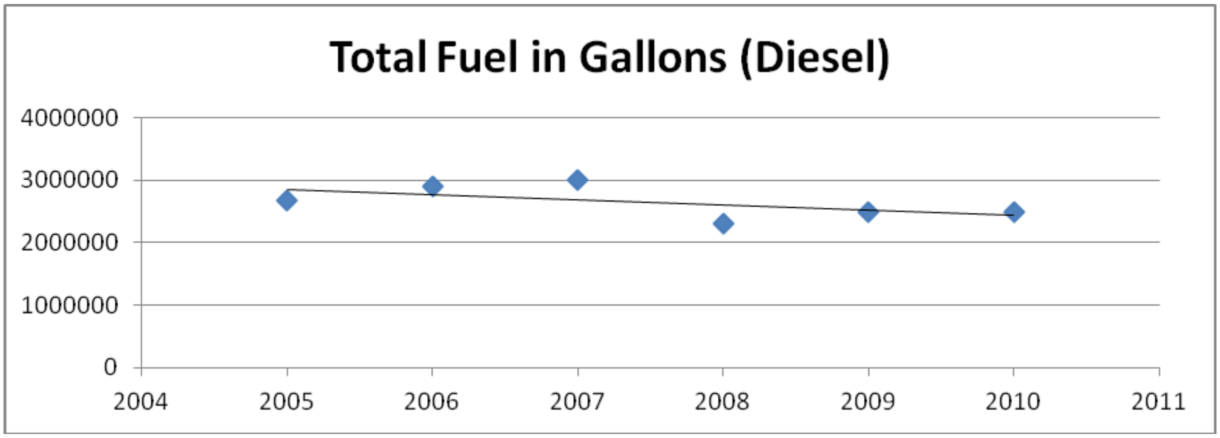


FIGURE 4.9
Total Gallons of Diesel Fuel Consumed in Each Year

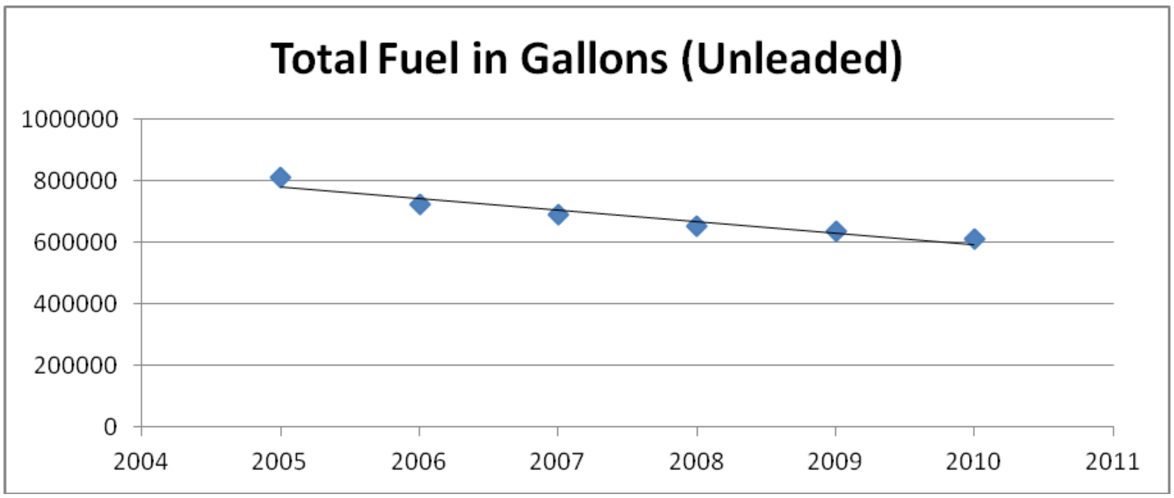


FIGURE 4.10
Total Gallons of Unleaded Fuel Consumed in Each Year

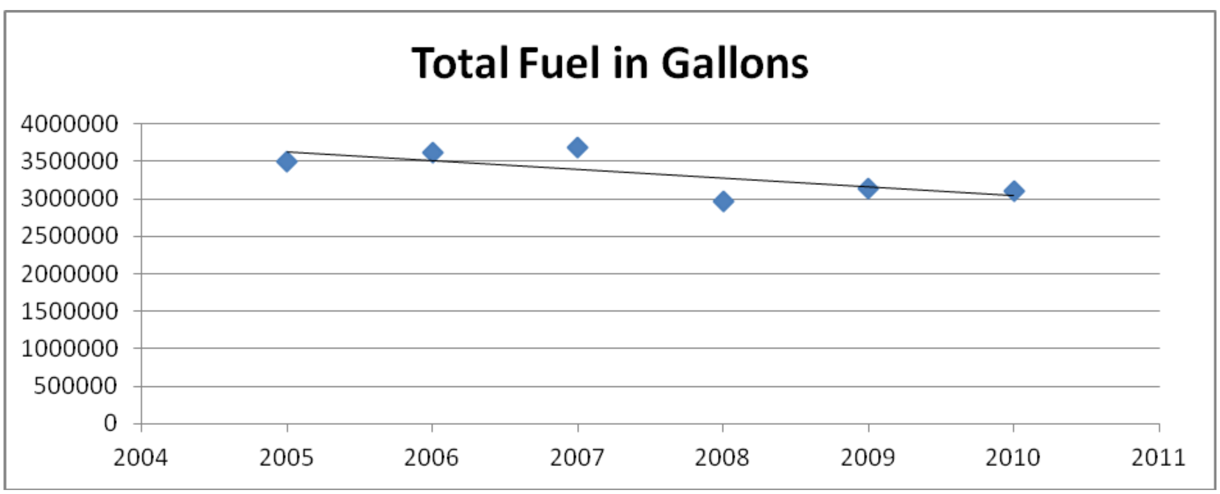


FIGURE 4.11
Total Gallons of Fuel Consumed in Each Year

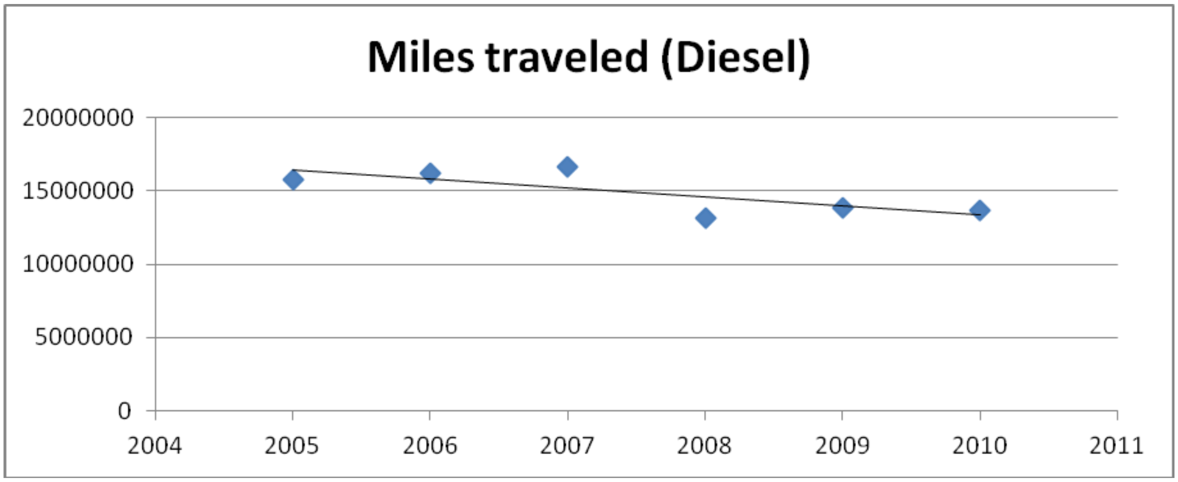


FIGURE 4.12
Total Miles Traveled in Diesel Vehicles for Each Fiscal Year

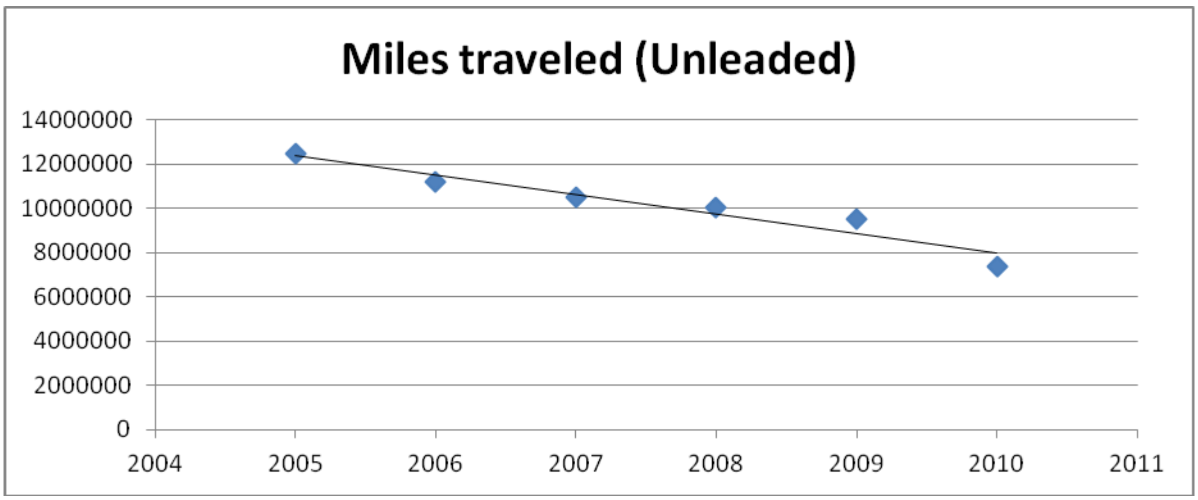


FIGURE 4.13
Total Miles Traveled in Unleaded Vehicles for Each Fiscal Year

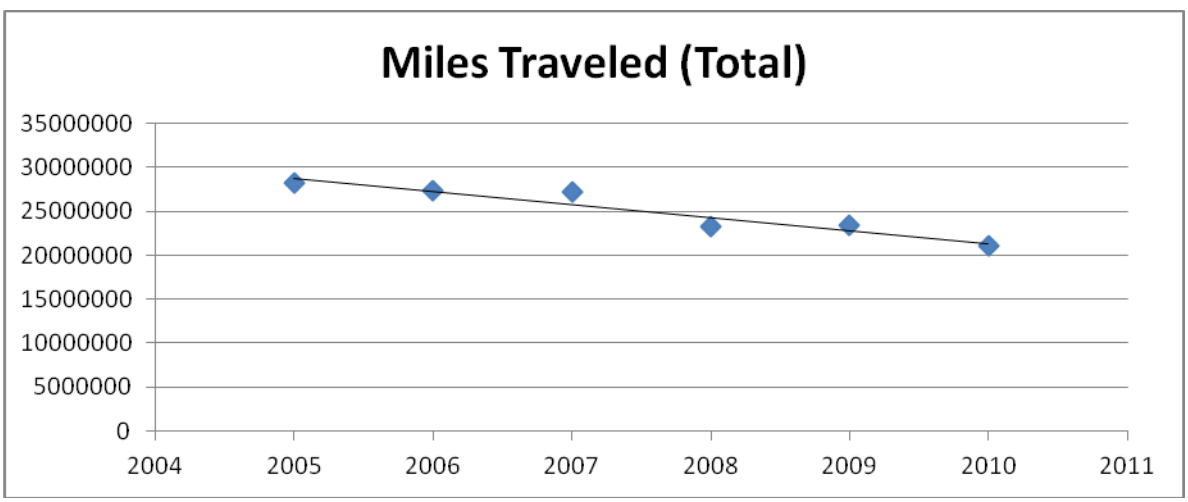
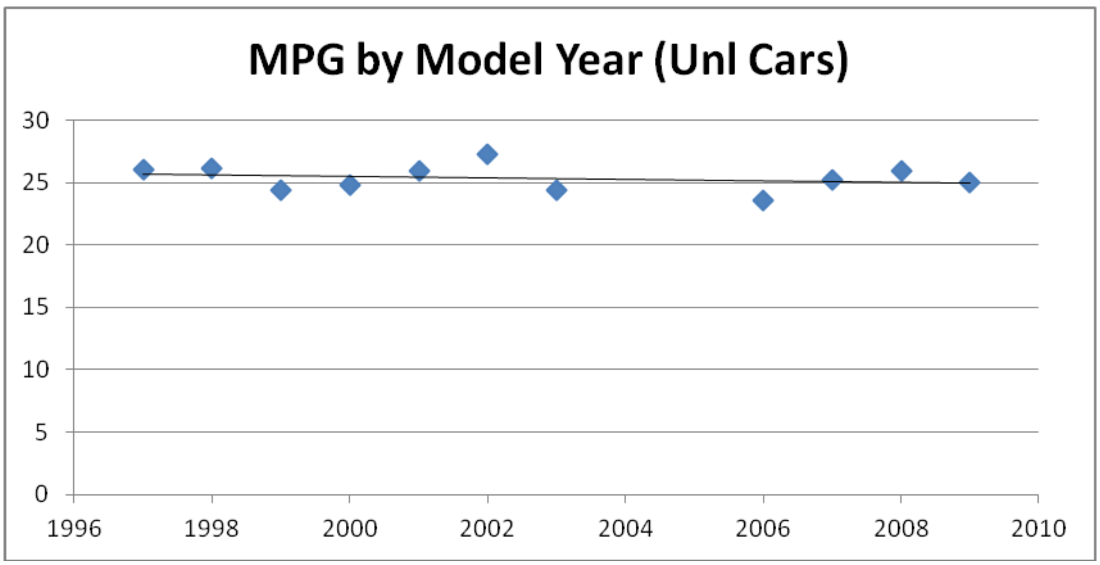


FIGURE 4.14
Total Miles Traveled in All Vehicles for Each Fiscal Year

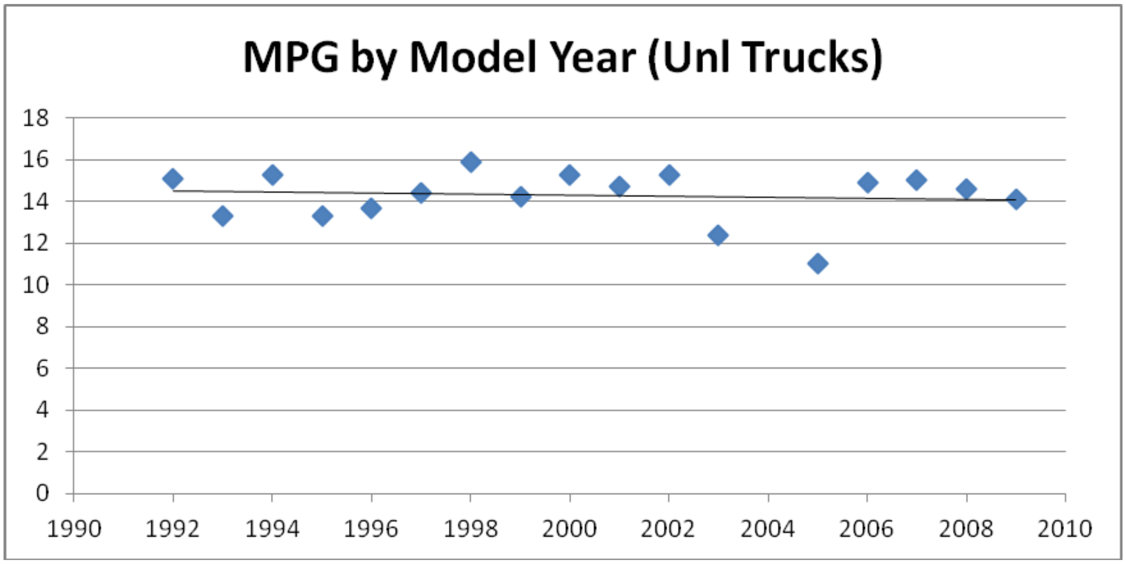
4.6 Accelerated Replacement Analysis

In light of the mandated increase in fuel efficiency of new vehicle models, we would generally expect that replacement of existing vehicles with newer models would improve overall performance with respect to fuel used per gallon travelled. Looking at the fuel usage (mpg) numbers in the database with respect to model year, we therefore expected to observe an increase in fuel efficiency in more recent model years. The actual records, however, did not show a significant increase in fuel efficiency for newer models and in fact showed a negative trend in fuel efficiency for several categories. Figures 4.15-4.18 show the average MPG for vehicles in major classes by model year.



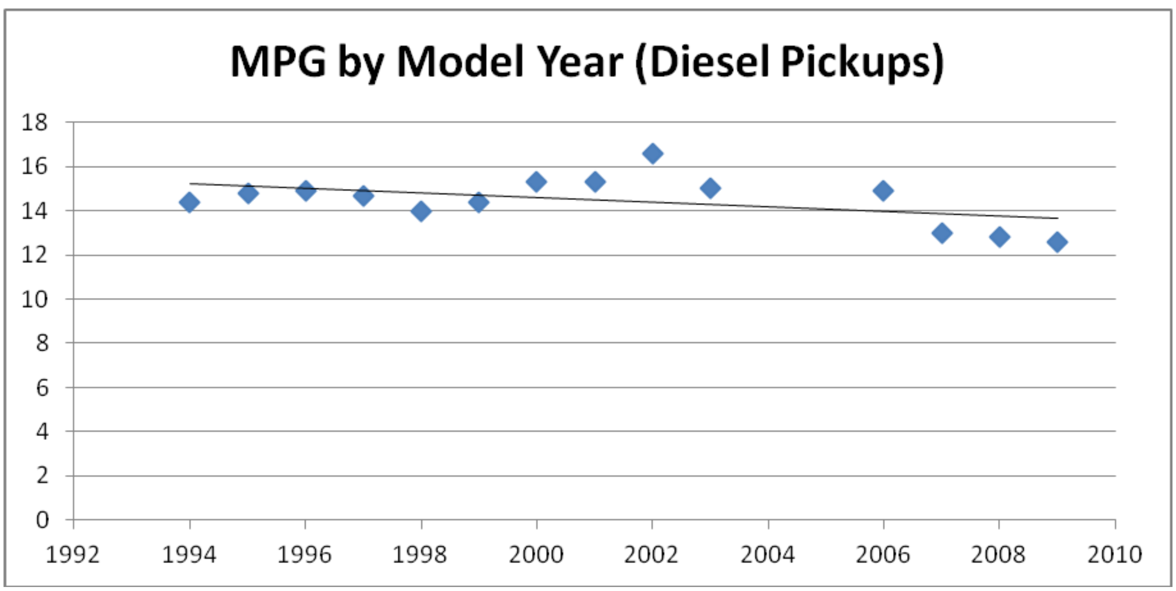
Note: The point for 1997 represents all cars model year 1997 and older.

FIGURE 4.15
MPG Efficiency for Each Model Year for Unleaded Cars



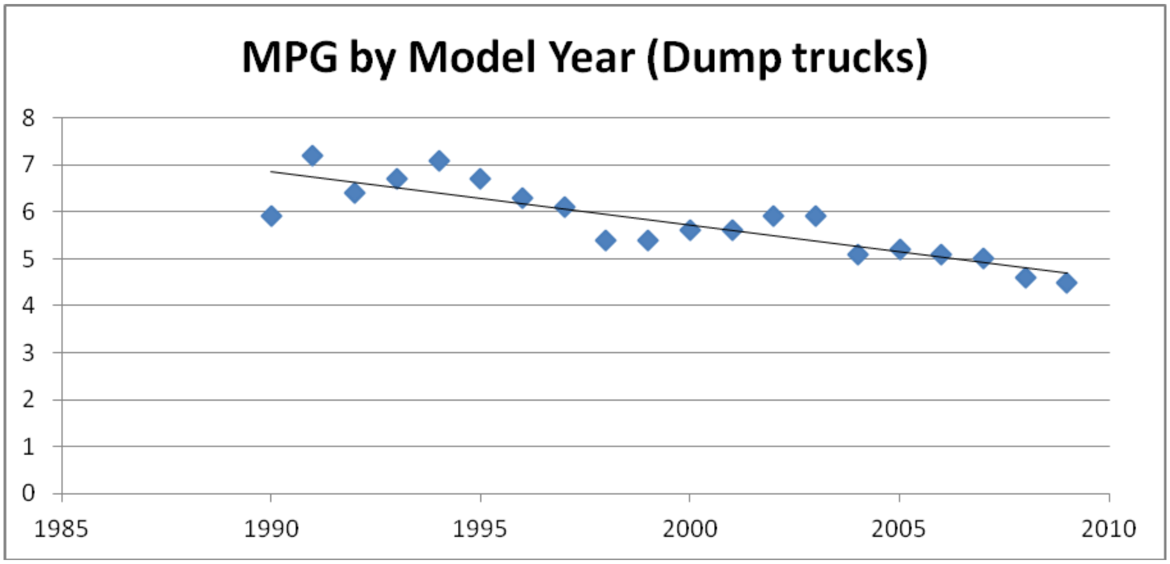
Note: The point for 1992 represents all unleaded trucks for model year 1992 and older.

FIGURE 4.16
MPG Efficiency for Each Model Year for Unleaded Trucks



Note: The point for 1994 represents all diesel pickups for model year 1994 and older.

FIGURE 4.17
MPG Efficiency for Each Model Year for Diesel Pickups



Note: The point for 1990 represents all dump trucks for model year 1990 and older.

FIGURE 4.18
MPG Efficiency for Each Model Year for Dump Trucks

The line of best fit for these data shows a slightly negative trend for unleaded cars and trucks, although the variation from year-to-year indicates this trend may not be significant. For diesel pickups there is decrease in fuel efficiency for vehicles after model year 2006, while dump trucks show a consistent negative trend in fuel efficiency for more recent models. These trends would suggest that replacing older vehicles with newer ones will not have a positive effect on fuel efficiency, and will negatively affect the overall MPG efficiency of KDOT's fleet in some cases, particularly 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.

4.7 Mileage Substitution Scenarios

Further analysis of the fuel database results was conducted to determine the effect of moving driving miles to more fuel efficient vehicles, specifically in the transportation related categories (diesel pickups, unleaded pickups and unleaded cars). The following calculations are based on a price of $3.35/gallon of unleaded and $3.60/gallon of diesel, the current prices at the time this work was carried out. Normal fluctuations in fuel prices will change these numbers somewhat, but the general trend is expected to stay the same, barring unforeseen breakthroughs or changes in production, demand, taxes, or mandates for a certain fuel. It is expected that diesel will cost slightly more per gallon than unleaded due to higher taxes, distribution costs, and extra refining steps, particularly sulfur removal. This assumption is supported since the June 2006 requirement of ultra-low sulfur diesel (ULSD) based on data made available by the U.S. Energy Information Administration (U.S. Energy Information Administration 2012).

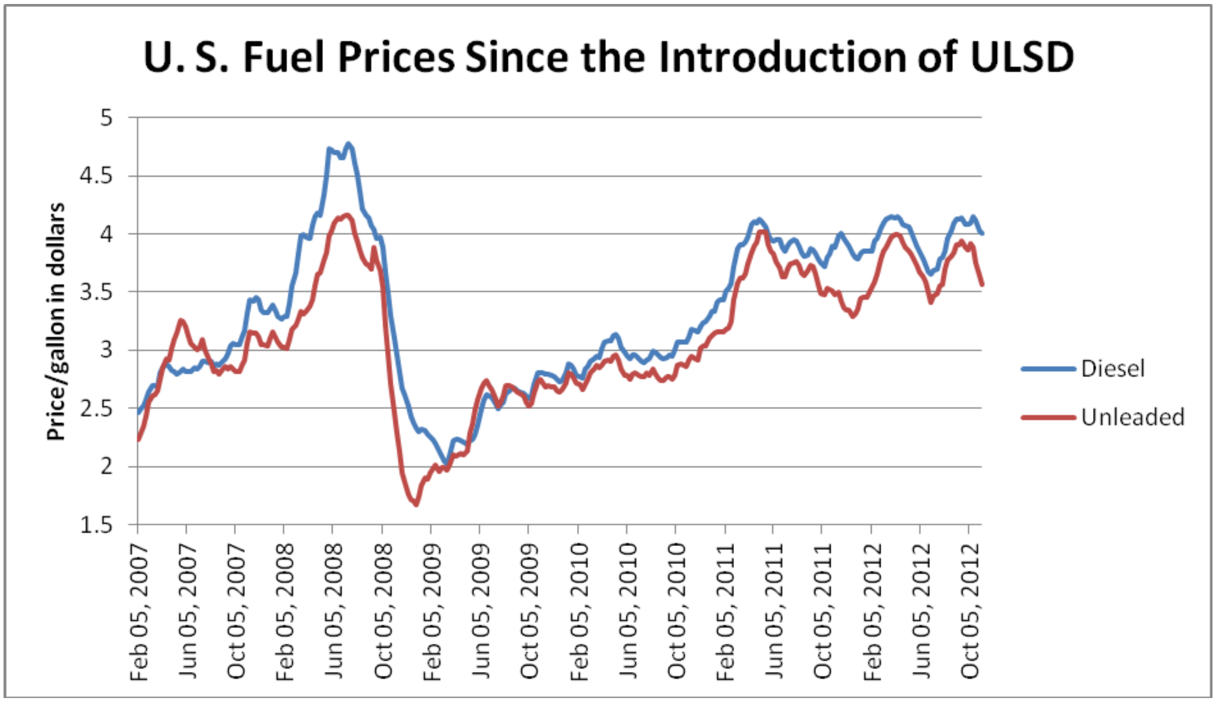


FIGURE 4.19
Weekly Data of National Average Prices per Gallon of Diesel and Unleaded Fuels since the Introduction of Ultra-Low Sulfur Diesel (ULSD)

A basic financial analysis of the different fuels and transportation vehicle types 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 4.3
Breakdown 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 4.4
Breakdown 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 presented in Table 4.5. As a reference, 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 a high energy content per amount used (MJ per gallon), per cost unit (MJ/$) and per pound of CO_2 released, while having a low energy expenditure per work produced, measured in this case as miles traveled (MJ/mile). Table 4.5 shows that unleaded fuel is more favorable than diesel both in term of emissions efficiency and energy required per mile of travel. (The MJ/mile value shown in parentheses is based on unleaded car efficiency, while the other values are for transportation trucks.) Unleaded does yield slightly less energy per dollar spent than diesel, but the higher efficiency of the unleaded vehicles makes up this difference. Fuels costs used were $3.60 and $3.35 per gallon of diesel and unleaded, respectively, as described above. As fuel price is highly variable, the cost efficiency relationship is not a constant value, although the ratio of diesel to gasoline costs will likely remain within a narrow range. All of the other numbers use constant values based on typical physical and chemical properties of diesel and unleaded fuels. Energy contents and CO_2 emissions factors were obtained from the Transportation Energy Data Book (Davis et al. 2012), while fuel efficiencies were obtained from our KDOT vehicle database calculations for diesel pickup trucks (14.3 mpg average), unleaded pickup trucks (14.5 mpg) and passenger cars (25.3 mpg).

TABLE 4.5
Breakdown of Fuel Performance in Terms of Energy in Megajoules (MJ) per Gallon, Dollar, Pounds of CO_2, and Miles Traveled

	Diesel	**Unleaded**
Energy content (MJ/gallon)	146.4	132.0
Cost efficiency (MJ/$)	40.67	39.39
Emissions efficiency (MJ/lb CO_2)	6.656	6.740
Work efficiency (MJ/mile)	10.43	9.11 (5.22)

The previous analysis highlights several significant findings for fuel efficiency and CO_2 emissions reductions. Obviously diesel has the greatest potential for savings and reduction, considering that it is the overwhelming majority of fuel used by KDOT. Additionally, on both an emissions and overall cost basis (when considering not only purchase price but also miles per gallon traveled), gasoline is seen to be a more efficient fuel than diesel. A few different options are therefore available for reducing both fuel use and CO_2 emissions.

Reductions could be achieved by an increase in efficiency of all the vehicles in KDOT's fleet. For the most part, this increase could most easily be influenced by their operators and by changes in operator behavior, such as reducing vehicle idling time and warm-up. This is complicated, however, by the wide range of vehicle types used by KDOT and the variations in environmental conditions under which work must be performed. Due to these variations, large scale guidelines for fuel reduction would be difficult to write or implement. Making operators aware of fuel efficiency issues and the potential for increased cost savings may be a more reasonable goal. Utilizing the fuel database, fuel use and efficiency for different vehicle categories could be tracked in subsequent years to assess fuel use trends and determine if any improvements have been achieved.

A more systematic and reliable measure that could be implemented, would be attempting to match work activities to the most fuel efficient vehicle capable of performing the specified job. As shown earlier, accelerated vehicle replacement does not appear to be effective for reducing fuel consumption on a similar model basis. However, as similar model vehicles become larger and more powerful, it may be possible to substitute some of the work typically done by these units with smaller, more fuel-efficient vehicles. One particular areas of focus, given their large contribution to overall fuel use and relatively low fuel efficiencies (around 5.6 mpg), would be to limit the use of dump trucks where possible, or explore purchasing lighter, more fuel-efficient models to replace some of the current work load.

Another area for possible savings, and one more directly calculable, would be to substitute some portion of general travel in pickups with travel in cars. Three scenarios were considered for these calculations: 1.) substitution of miles traveled in unleaded pickups with passenger cars; 2.) substitution of miles traveled in diesel pickups with passenger cars; and 3.) substitution of miles traveled in diesel pickups with unleaded pickups. The following figures show how substituting a small percentage of total vehicle miles can have dramatic effects on fuel consumption and CO_2 emissions. The scenarios model overall travel mile reductions, rather than attempting to identify specific cases where substitution can occur. This is because the requirements for a pickup truck vs. passenger car, or a diesel vs. unleaded truck, may be very job specific. The truck to passenger car substitutions (scenarios 1 and 2) represent an effort to use more fuel efficient vehicles for cases where transport of personnel from one place to another is the major consideration in which vehicle to use. Of course, some jobs will require the higher engine power, carrying capacity or off-pavement driving capabilities of a pickup and cannot be easily substituted. A third scenario 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, but it still allows access to trucks for tasks that may be too heavy duty for cars. All scenarios were conducted over the entire six years (FY 2005 through FY 2011) of data available in the KDOT database. The final number at each point therefore represents total savings (gallons of fuels, $, or CO_2 emissions reductions) over this time period.

All calculations shown in Figures 4.20-4.28 use a similar procedure, substituting a different % of miles converted and appropriate MPG, cost and CO_2 emissions factors. For example, 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. Dividing the number of miles by the MPG efficiency of both unleaded trucks (14.5) and cars (25.3) gives the total number of gallons of fuel required to travel the 8 million miles under both conditions. The total fuel savings (in gallons per year) is then found by subtracting these two values (556,705 (trucks) – 319,060 (cars)). The subsequent reduction in CO_2 emissions was obtained by multiplying the gallons used for both cars and trucks by the EPA estimated CO_2 emissions factors of 19.6 lbs CO_2/gallon gasoline and 22.4lbs CO_2/gallon diesel (U.S. EPA 2011), and again calculating the difference. In this example, CO_2 savings would be about 2174 tons. Analogous calculations for monetary savings yield about $800,000 saved @ $3.35/gallon of unleaded fuel vs. $3.60 per gallon diesel. 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.

For scenarios involving substitution of gasoline for diesel fuel, we also accounted for the additional differences in fuel properties. 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 due to compositional and density differences (Davis et al. 2012). As a result, a gallon of diesel and a gallon of unleaded are not the same in terms of energy or CO_2 produced. Therefore, the calculation of gallons saved from diesel to gasoline substitution was not used directly in subsequent calculations of price or CO_2. Instead, the total diesel or total unleaded that would be required for miles driven (based on the database 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, however, account for the differences in diesel and gasoline based on the different cost ratios and emission factors used. Thus, these values are more accurate ways to compare the scenarios involving gasoline for diesel substitution. For the unleaded trucks to passenger cars scenario, all three measures are equally useful. The graphs showing the results for fuel savings, CO_2 emissions reductions, and cost savings are shown on the following pages.

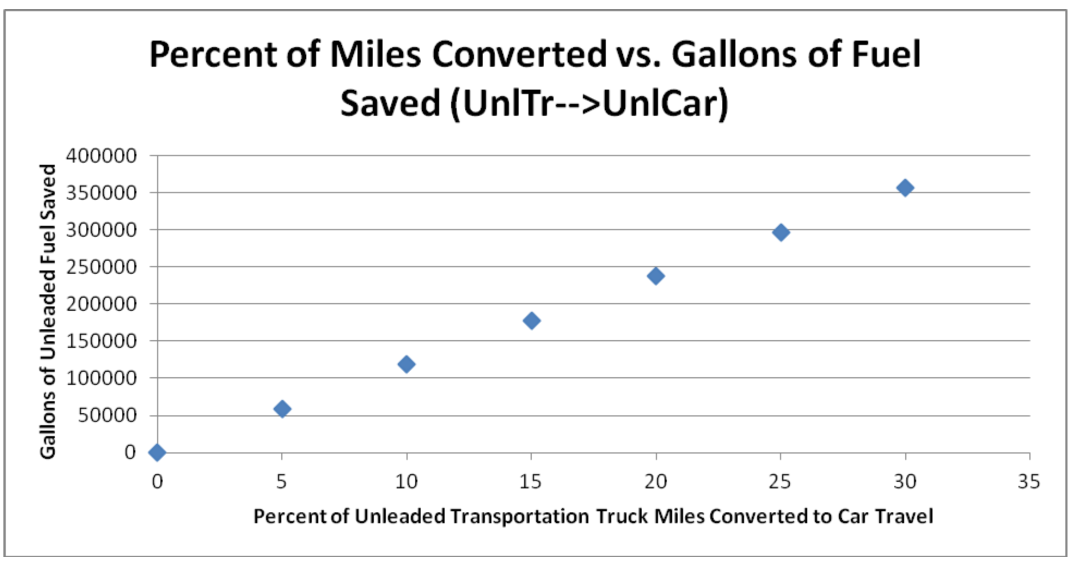
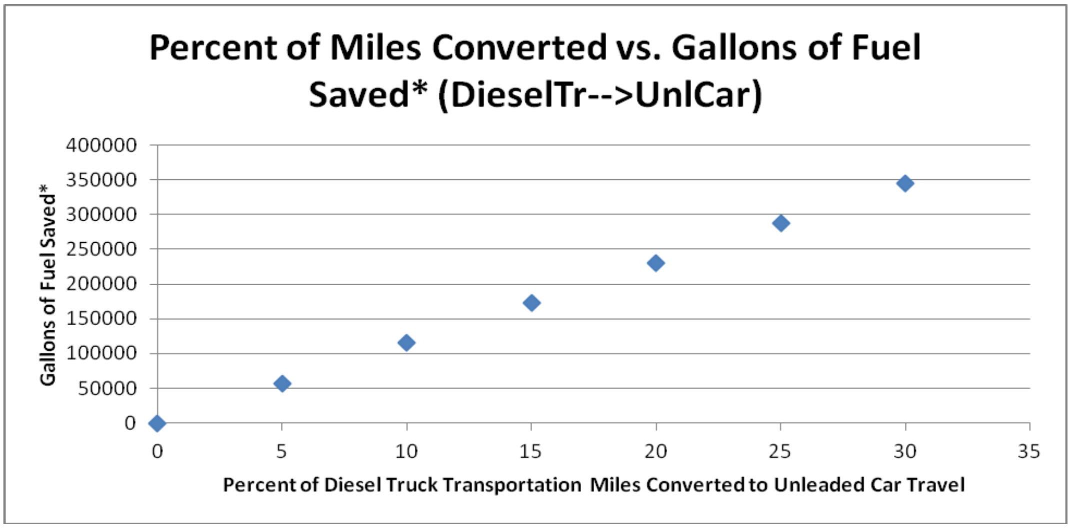
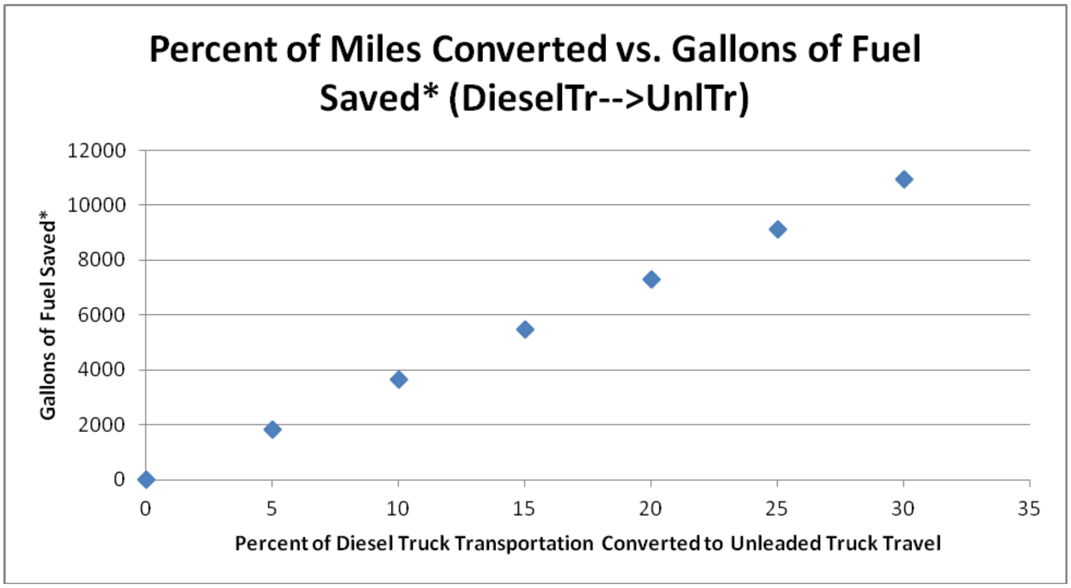


FIGURE 4.20
Gallons of Unleaded Fuel That Would Have Been Saved for Scenario 1 (Passenger Cars Substituted for Unleaded Trucks) As a Function of % of Truck Miles Replaced



Note: Asterisk denotes that diesel and gasoline fuel volumes are not directly comparable, as described above.

FIGURE 4.21
Gallons of Unleaded Fuel That Would Have Been Saved for Scenario 2 (Passenger Cars Substituted for Diesel Trucks) As a Function of % of Truck Miles Replaced



Note: Asterisk denotes that diesel and gasoline fuel volumes are not directly comparable, as described above.

FIGURE 4.22
Gallons of Diesel Fuel That Would Have Been Saved for Scenario 3 (Unleaded Trucks Substituted for Diesel Trucks) As a Function of % of Diesel Truck Miles Replaced

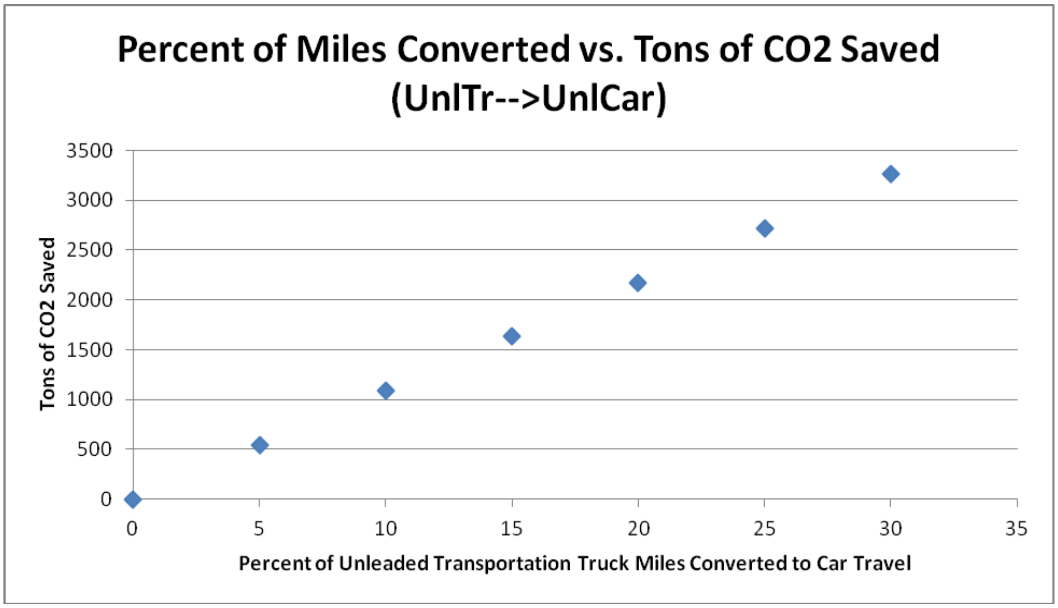


FIGURE 4.23
Graph Representing the Tons of CO_2 That Would Have Been Saved for Scenario 1 (Passenger Cars Substituted for Unleaded Trucks) As a Function of % of Truck Miles Replaced

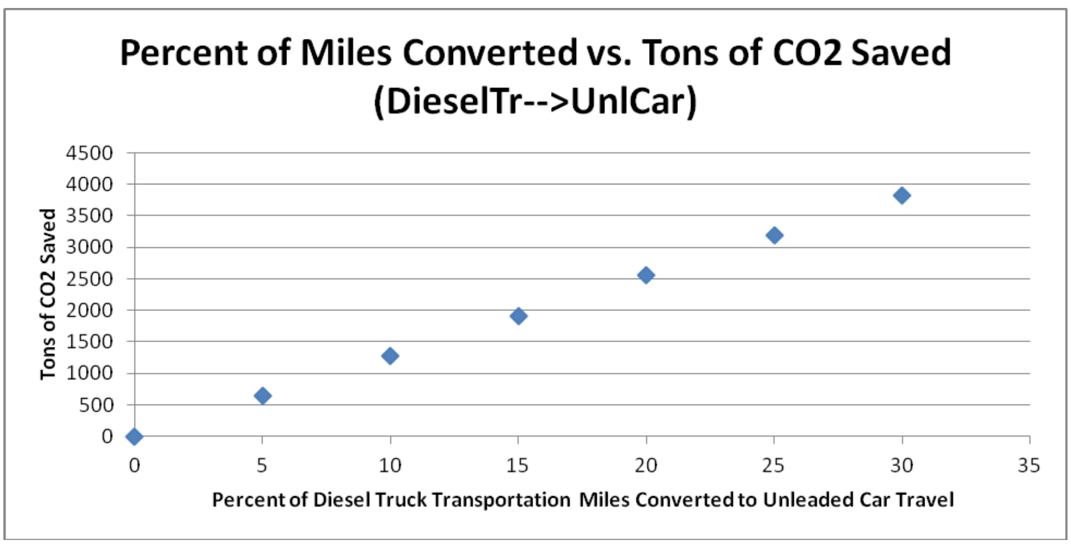


FIGURE 4.24
Graph Representing the Tons of CO_2 That Would Have Been Saved for Scenario 2 (Passenger Cars Substituted for Diesel Trucks) As a Function of % of Truck Miles Replaced

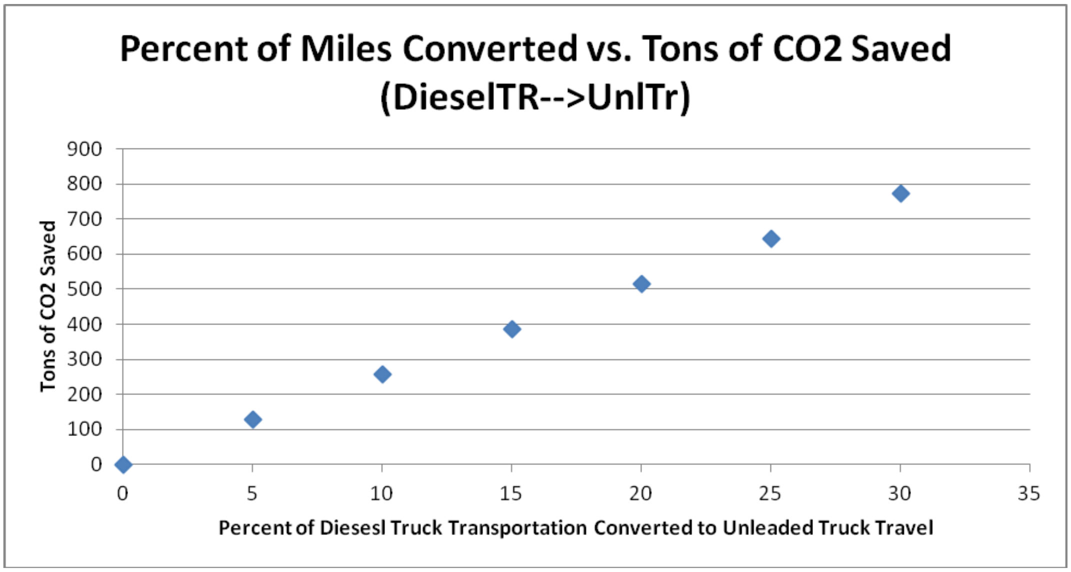


FIGURE 4.25
Graph Representing the Tons of CO_2 That Would Have Been Saved for Scenario 3 (Unleaded Trucks Substituted for Diesel Trucks) As a Function of % of Diesel Truck Miles Replaced

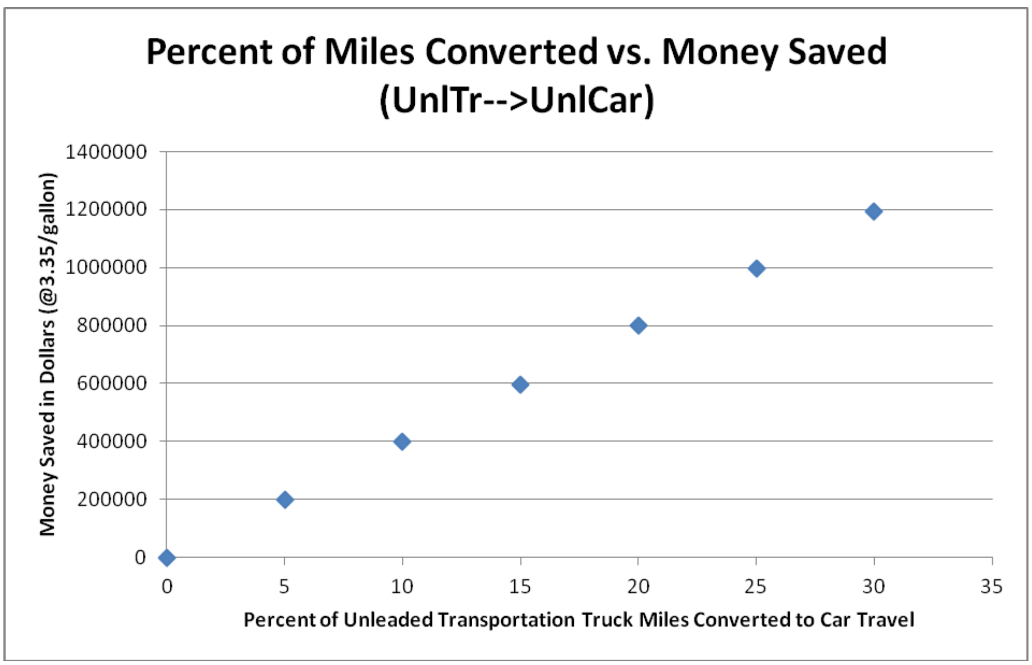


FIGURE 4.26
Graph Representing the Money That Would Have Been Saved for Scenario 1 (Passenger Cars Substituted for Unleaded Trucks) As a Function of % of Truck Miles Replaced

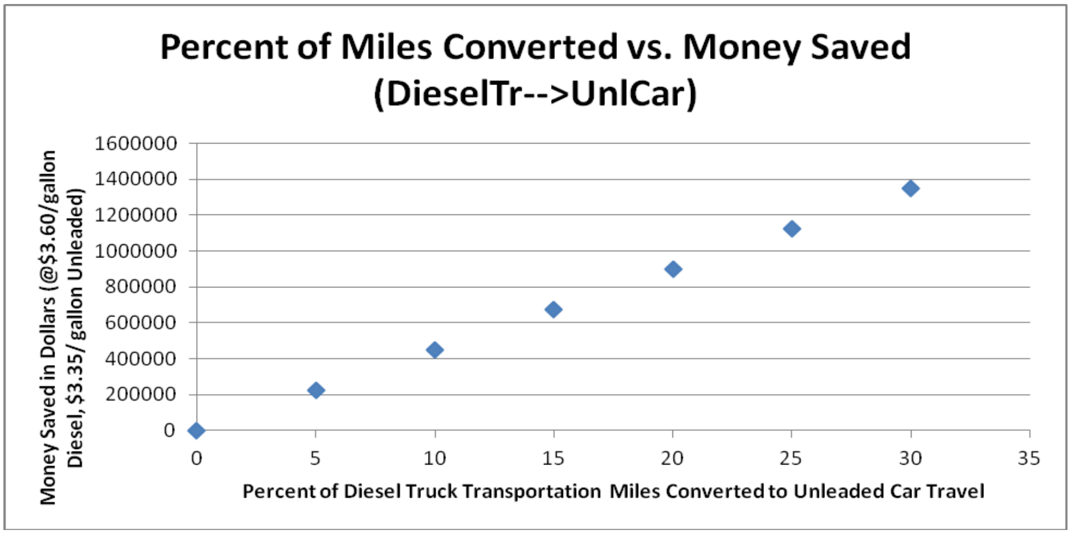


FIGURE 4.27
Graph Representing the Money That Would Have Been Saved for Scenario 2 (Passenger Cars Substituted for Diesel Trucks) As a Function of % of Truck Miles Replaced

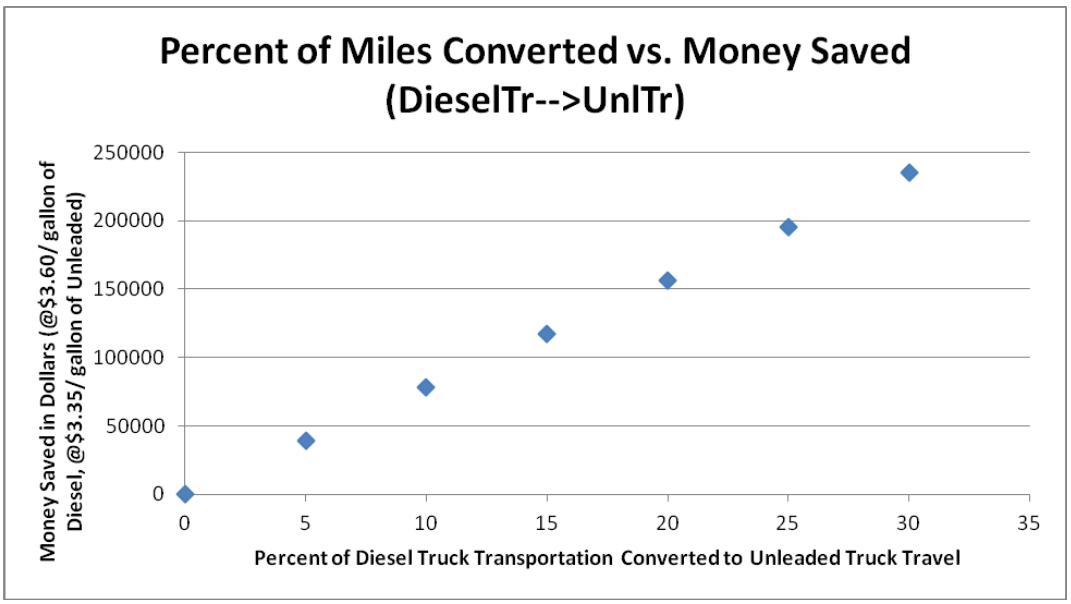


FIGURE 4.28
Graph Representing the Money That Would Have Been Saved Based for Scenario 3 (Unleaded Trucks Substituted for Diesel Trucks) As a Function of % of Diesel Truck Miles Replaced

If we assume a constant reduction in all variables across the six year timespan, Scenario 1 would result in a savings of approximately $67,000 and 200 tons CO_2 per year at only 10%

substitution of car miles for truck miles. Scenario 2 would result in similar savings. The savings from converting diesel truck miles to unleaded truck miles (Scenario 3) is not nearly as great, estimated at $13,000 and 47 tons CO_2 per year at 10% substitution, as the difference in truck fuel efficiency is relatively small. 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. In addition, similar measures to limit the use of larger vehicles and equipment (especially dump trucks) could result in additional savings.

4.8 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 2012). 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). The specific properties of biodiesel will be described in more detail later.

The term "biofuels" is an appropriate name because, ultimately, fuels are obtained after a number of steps from a starting materials 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 in a reasonable timeframe and a portion of the carbon is recycled, as described further below. 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.

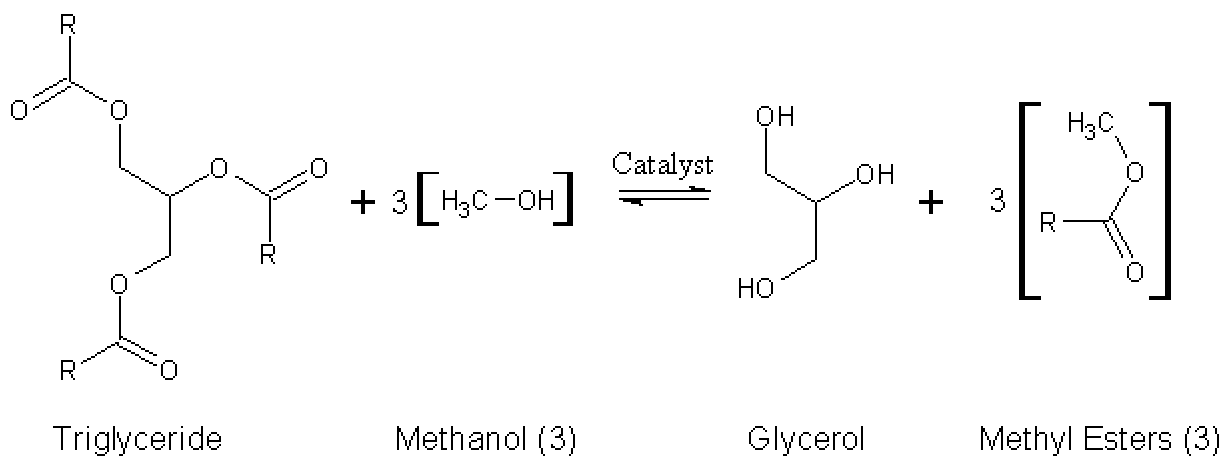
Biofuels are not a miracle discovery to reduce all combustion emissions, however. These fuels still result in the combustion of organic molecules to produce CO_2 and water, just like petroleum products. To assess biofuel CO_2 emissions, therefore, a larger picture must be considered, typically done using 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 the CO_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 et al. 2009). The EPA currently requires that a renewable fuel must reduce net CO_2 emissions by 50% compared to a baseline 2005 petroleum diesel using a specified LCA methodology. Using this criteria, some biodiesel fuels, including soy-based biodiesels, are classified as renewable fuels (U.S. EPA 2010). 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.

4.9 Biodiesel Properties

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. Biodiesel typically consists primarily of straight chain hydrocarbons with ten to twenty carbon atoms per molecule (Knothe et al. 2005), while petroleum diesel contains a more diverse range of compounds, including more branched and ringed molecules. 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 presence of oxygen in 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.



(Source: Image available on Wikipedia at the address below and made available through a Creative Commons license (**http://en.wikipedia.org/wiki/File:Generic_Biodiesel_Reaction1.gif**)

FIGURE 4.29
General Chemical Reaction for Conversion of Triglycerides (Vegetable Oils) to Biodiesel and Glycerol

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, so this produces some additional air quality benefits from biodiesel combustion.

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 existing 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 this difference in viscosity. The specific problems include cloud point, pour point, and melting point. All three of these properties are closely related, as they are all relate to 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 4.6 shows the cloud points for both petroleum and biodiesel. In most of the United States, 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 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 (Tat and Van Gerpen 1999; Valeri and Meirelles 1997), 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 in Figure 4.30 in a representative petroleum molecule prevents the molecules from becoming too packed together in a regular structure (Hong 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 2011). 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.

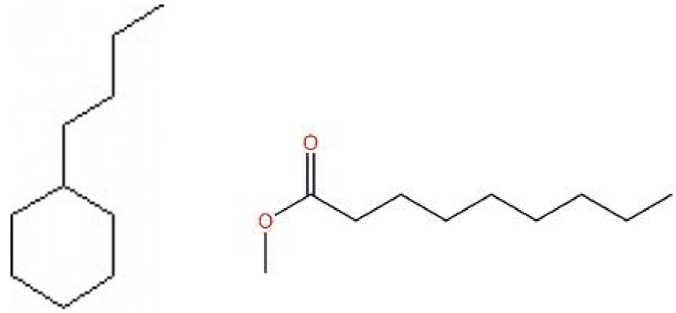


FIGURE 4.30
A Typical Petroleum Diesel Molecule (Left) and a Typical Biodiesel Molecule (Right)

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. Table 4.6, adapted from Sadashivam (2007) provides a snapshot of many of the properties already discussed.

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.

TABLE 4.6
Various Properties of Petroleum Diesel and Pure Biodiesel, After

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

(Source: Sadashivam 2007)

Another relevant 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 most widespread and relevant example of material compatibility issues with biodiesel is natural rubber which was commonly used in vehicles before 1993 (National Biodiesel Board).The hoses and gaskets in the fuel transport system will rapidly break down in the presence of pure biodiesel. Vehicles produced after 1994 commonly use Teflon or Nylon instead in the fuel transport system, so this compatibility issue is not observed. Other materials that can display negative effects of this solvent ability include neoprene, nitrile, and styrene. 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 (National Biodiesel Board). Generally, lower biodiesel blends display lesser compatibility issues, with B2 to B5 blends showing little to no effect on materials compatibility (NREL 2009).

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 departments of transportation (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 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, although these additives can also affect fuel flash point, and therefore handling and safety requirements (NREL 2009). Cold weather 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. While it provides necessary minimums for reliable fuel performance, the ASTM criteria neglect many crucial aspects that need to be considered for practical reasons, particularly storage. Storing the fuel for varying periods of time can result in a change in the fuel composition and performance. Biodiesel blends are more likely than petroleum diesel to degrade over time due to the oxygen content of the biodiesel fuel. While this is not typically an issue for regular operation, stability additives and monthly acidity tests are recommended for biodiesel blends that are stored for extended periods (NREL 2009). Higher temperatures increase biodiesel instability (defined here as the ability of the fuel to the ability of the fuel to oxidize and breakdown or polymerize over time without the introduction of any other chemicals or conditions), while lower biodiesel blends are more resistant to chemical breakdown (Shang 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 et al. 2012). An additional issue not addressed by existing standards is microbial activity. Biological activity is possible in both petroleum diesel and biodiesel but to a much higher degree in biodiesel due to the simpler molecules and fuel oxygen content, which are more conducive to microbial growth

(Dodos et al. 2012). Biocides may be needed to be used to control microbial growth in storage containers for high biodiesel content fuels.

The BQ-9000 process, developed by the National Biodiesel Accreditation Commission, a committee of the National Biodiesel Board, is a relatively new process for certifying bidiesel producers, marketers and testing laboratories (National Biodiesel Accreditation Commission 2012). This certification process evaluation is designed to provide standardization for biodiesel shipping, storage, blending, testing and fuel management procedures, in addition to the basic fuel property requirements covered by ASTM-D6751. 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”. 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. If these requirements are passed, then the lab or producer can become BQ-9000 Certified. BQ-9000 could be helpful in addressing the regular testing of stored biodiesel to ensure quality over time, through the establishment of certified laboratories, and also in expediting the purchase and production from certified producers.

Chapter 5: Recommendations

The work done in this study analyzed fuel and maintenance records in a Microsoft Access database. This analysis brought to light several 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 to 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. Continued updating of the database and use of the query and analytical functions already in place will allow KDOT to monitor changes in fuel consumption and CO_2 emissions due to fuel use, and perform 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. Additionally, minimizing the use of low MPG vehicles, such as dump trucks, wherever possible will increase fuel savings.

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 in a given set of vehicles. 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. The BQ-9000 certification process should be studied to determine if it addresses KDOT needs with regards to fuel suppliers and testing. If the program is suitable, adopting BQ-9000 certification requirements for biodiesel producers and testing laboratories could help reduce issues with fuel quality and testing requirements.

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 could help stimulate development of local biofuel production capacity, potentially reducing future purchase costs. Using biofuels can also help lessen the impact of KDOT's CO_2 footprint, and is only a step along the way toward a more fully sustainable energy supply. With the current fiscal guidelines for purchasing biofuels ensuring that KDOT does not suffer significant additional costs from biodiesel purchasing, there is minimal 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, provided a reasonable cost comparison exists between biodiesel and petroleum diesel fuels, and even try to increase their use with higher blends up to B10 or B20 when possible, such as during 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.

One additional area of analysis made possible by this database would be the impacts of reduced KDOT fuel use (or increased biodiesel substitution) on other vehicle exhaust pollutants, such as NO_x, total hydrocarbons, and particulate matter. EPA published emission factors for most other regulated pollutants similar to the ones used for CO_2 in this study. Simple calculations from total fuel use numbers generated by the Fuel Records Database could produce estimates for reduction in total emissions of these pollutants due to changes in fuel consumption patterns. Since these pollutants can produce adverse health effects, reducing fuel consumption can improve ambient air quality and promote respiratory health, particularly in urban environments or where KDOT activities are prevalent.

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Appendix A: KDOT Power Usage Website Manual

In a web browser, go to http://www2.ku.edu/~sims/cgi-bin/KDOT/index.php. The main page shows the option main page for analysis as shown in Figure A.1.

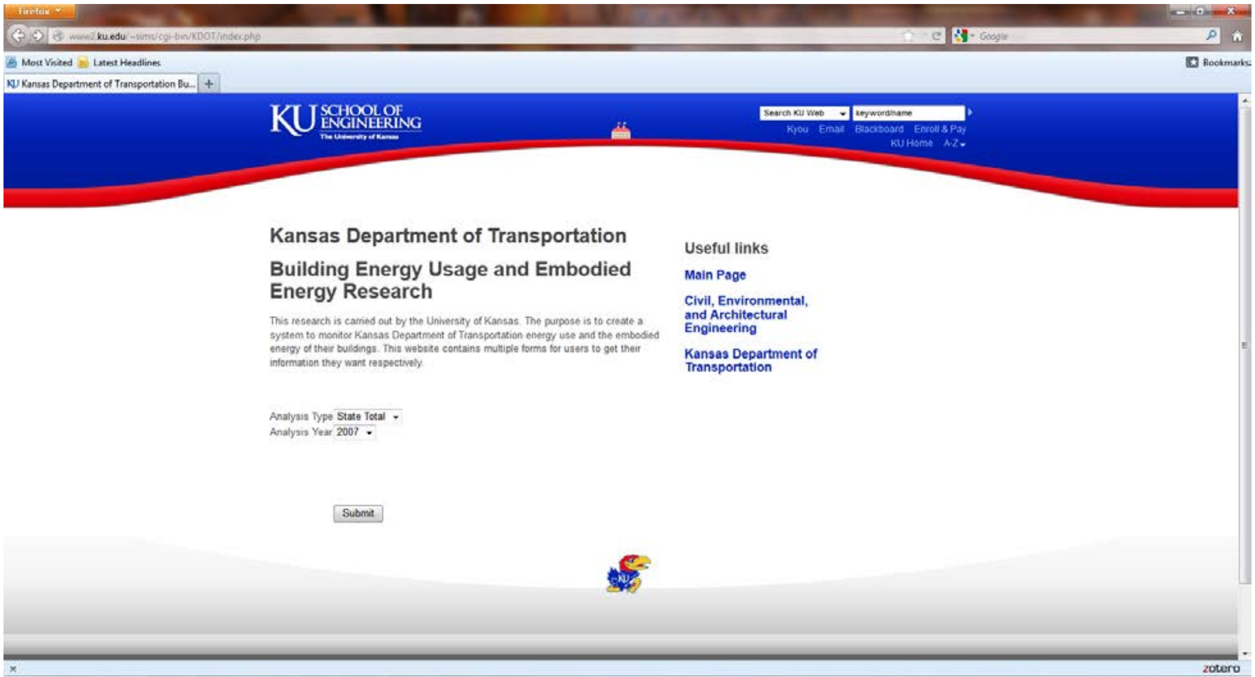

FIGURE A.1
Website Main Page

In this page, the options of analysis type can be chosen. These options are: State Total, District, County, City, and Zip Code. With the State Total analysis type the only option shown is the analysis year (2007-2010). With the other four totals, another option is shown to specify the wanted city, county, or zip code. The county option is shown in Figure A.2.

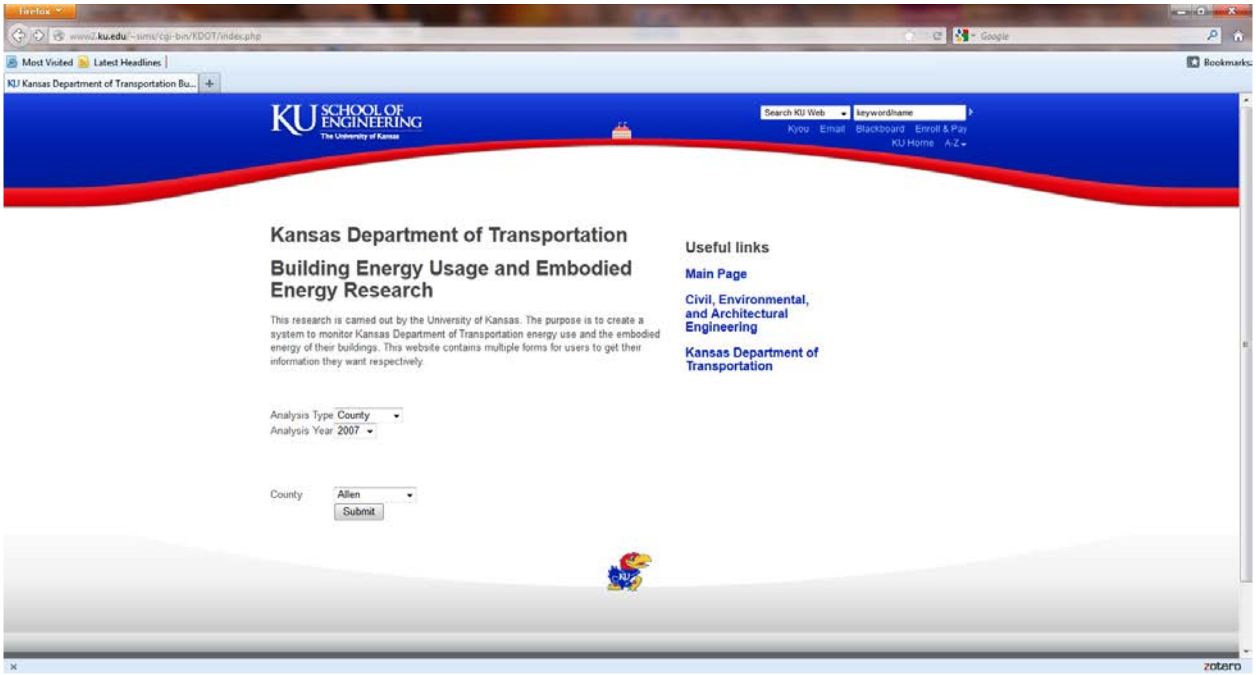

FIGURE A.2
Main Page With County Option Selected

For example, the Douglas county for the year of 2009 was chosen. With this inputted, the results are shown in Figure A.3 and A.4.

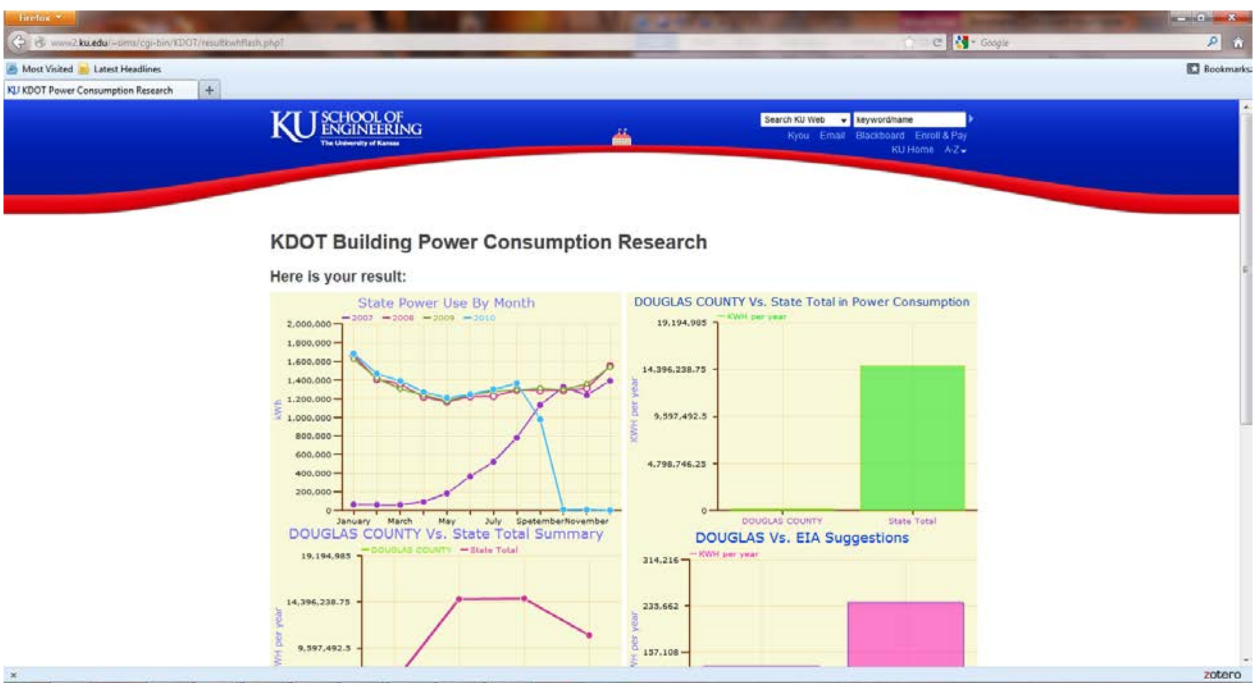

FIGURE A.3
Results Page (Top)

FIGURE A.4
Results Page (Bottom)

With the results, highlight a node on line graphs or a bar on the bar graphs, the actual data aquired is shown in Figure A.5.

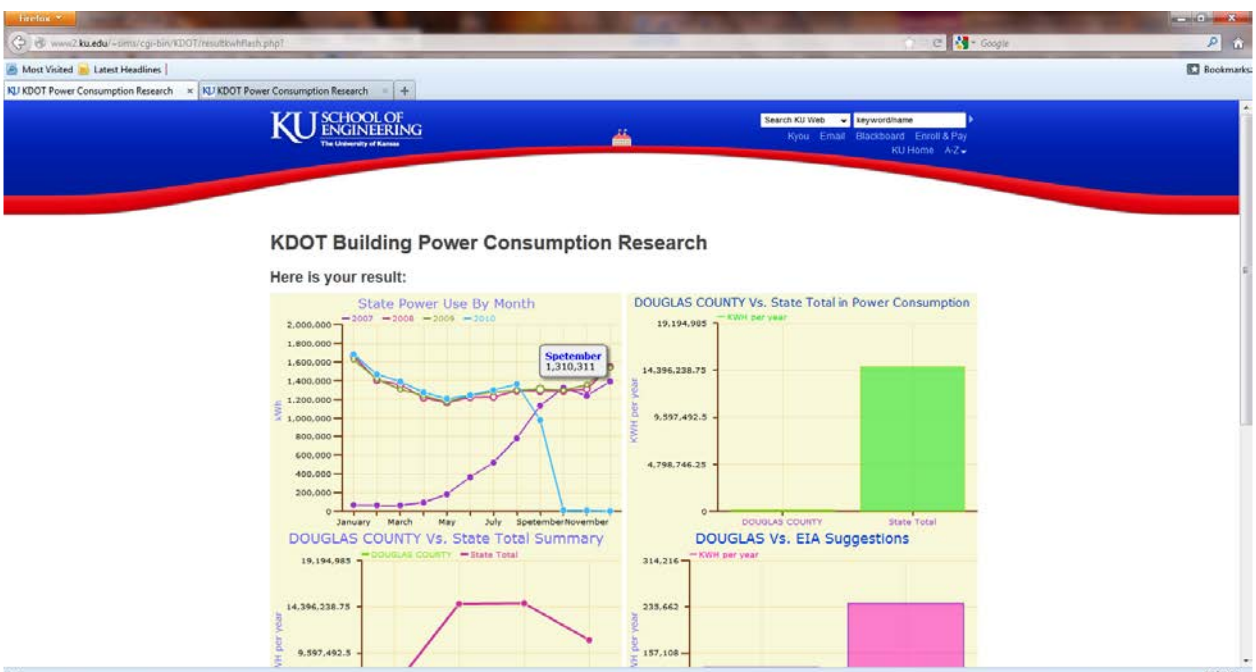

FIGURE A.5
Results Page Highlighting Node Data

On the bottom of the results page are the links to energy reduction methods, embodied carbon results, and return to the data selection page. The embodied carbon graphs work the same as the utilty results page.

Appendix B: Instructions for Using The 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”.

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