NATIONAL RENEWABLE ENERGY LABORATORY

# MEMO

**Date:** October 2, 2017

**To:** City of Denton, Texas

**From:** Cities Leading through Energy Analysis and Planning (Cities-LEAP), National Renewable Energy Laboratory (NREL)

**Subject:** City Energy: From Data to Decisions—Denton, Texas

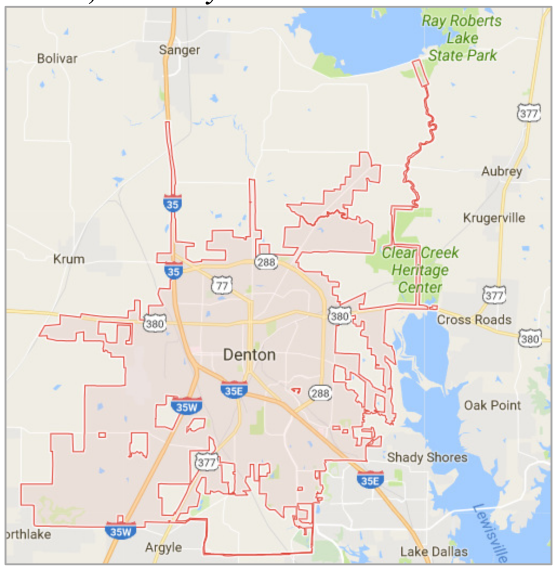
## Background

The U.S. Department of Energy's (DOE's) Cities Leading through Energy Analysis and Planning (Cities-LEAP) and State and Local Energy Data (SLED) programs, along with the National Renewable Energy Laboratory (NREL), partnered with 10 U.S. cities to demonstrate how Cities-LEAP and SLED data and analysis can enable more strategic energy decisions. This fact sheet shows how NREL and the City of Denton used data from resources including City Energy Profiles on the SLED website (eere.energy.gov/sled) to inform strategies to meet their city energy goals. Cities across the country can follow the same approach for their own energy planning.

*A portion of the methodologies used to generate data, results, conclusions, and interpretations presented in this document have not been reviewed by technical experts outside NREL or the City of Denton.*

# City Energy: From Data to Decisions—Denton, Texas

***Denton, Texas City Boundaries***




*Source: Google Maps*

## City Energy Question and Goals

As Denton, Texas, embarks on an update to its 2012 sustainability plan and greenhouse gas inventory, the city is seeking to address significant local air quality concerns. Vehicle emissions rank among the largest sources of smog, soot, and other air pollutants. The City of Denton needed data and analysis on fuel consumption, vehicle miles traveled (VMT), and related transportation indicators to help target actions to improve local air quality.

Additionally, having seen the impact of its green building code on new construction and renovations, the City of Denton is also seeking to extend energy efficiency benefits to low- and moderate-income (LMI) households, many of which are in older homes and cannot afford efficiency upgrades and renovations. To this end, the city asked for data and analysis to help them target actions and policies that could have the greatest benefit for low-income households.

## Data and Analysis

Previously, Denton relied on regional transportation data supplied by the North Central Texas Council of Governments. As that data set is not city-specific, applying it to Denton can be difficult. As part of the Cities-LEAP project, NREL developed robust, city-specific data estimates on VMT and fuel consumption, which are available on SLED and are used for this analysis.

Estimated city energy data available on the SLED website (eere.energy/gov/sled), supplemental data from publicly available sources, and data inputs obtained directly from the City of Denton provide the foundation for this analysis.[1]

# 1 Vehicles Miles Traveled and Fuel Consumption

According to the data on SLED, Denton's estimated total VMT was 1.04 billion in 2013, or approximately 9,200 vehicle miles traveled per person. Interstate and arterial VMT account for an estimated 46% and 44% of total VMT, respectively, with collector roads making up the remaining 10% (Figure 1).

[1] See Appendix A for transportation data methodology and Appendix B for low-income data and analysis methodology.

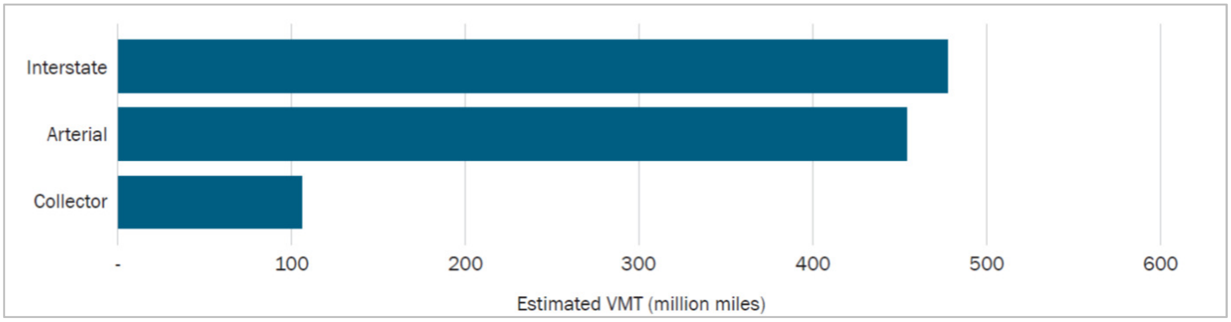



**Figure 1. Annual vehicle miles traveled (VMT) by road class (2013) for Denton, Texas, from SLED**

Denton's estimated on-road vehicle fuel use is well above average compared to the 211 cities with similar population sizes and climate zones (cohort cities)[2] generated by a SLED algorithm (see Figure 2). Estimated gasoline use of 56,500,000 gallons in 2013 is approximately 88% higher than the cohort average, and the estimated 18,700,000 gallons of diesel use is approximately 205% higher than average for similarly sized cities.

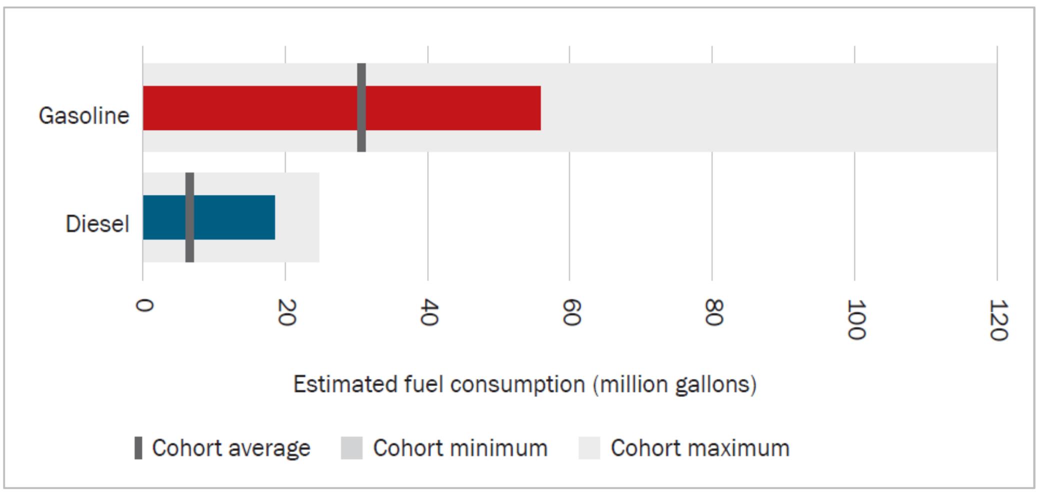



**Figure 2. Annual on-road vehicle fuel use (light, medium, and heavy duty) by fuel type (2013) for Denton, Texas, from SLED**

Compared to nearby Texas cities (Table 1), total and per capita VMT and fuel consumption in Denton fall below that in Dallas and Fort Worth. This comparison also reveals the extent to which population and the length of interstate highway road segments within city limits are major predictive factors in the methodology used to estimate VMT.

[2] Climate zones are based on definitions developed by Pacific Northwest National Laboratory. The data sources and methodologies used to determine cohort cities and estimate fuel consumption and VMT are available on SLED.

**Table 1. Estimated Annual VMT and On-Road Vehicle Fuel Use for Denton, Texas, and Nearby Cities**

| | Denton | Dallas | Fort Worth | McKinney |
|---|---|---|---|---|
| VMT/capita | 9,200 | 10,100 | 9,700 | 4,500 |
| Total VMT | 1,037,335,200 | 12,006,250,000 | 7,011,583,000 | 568,332,400 |
| On-road vehicle gasoline consumption/ capita (gal) | 450 | 530 | 490 | 210 |
| On-road vehicle diesel consumption/ capital (gal) | 150 | 160 | 140 | 75 |
| Total on-road vehicle gasoline consumption/ year (gal) | 56,496,900 | 665,847,200 | 388,905,400 | 31,120,500 |
| Total on-road vehicle diesel consumption/ year (gal) | 18,702,900 | 202,027,300 | 113,450,800 | 11,123,800 |

*Data from SLED and in-house R.L. Polk & Company data (2013).*

To better understand Denton in relation to similar cities that are integrated with nearby metro areas and therefore integrated in air quality, we compared Denton with five other western cities with comparable populations that are also located within major metropolitan areas (Table 2). This limited comparison indicates that Denton has higher total VMT and VMT per capita than these comparable cities and illustrates the influence of population density.

**Table 2. Estimated Annual VMT and Population Density for Denton, Texas and Peer Cities (2013)**

| | VMT/Capita | Total VMT | Population/land area ($km^2$) |
|---|---|---|---|
| Denton, Texas | 9,200 | 1,037,335,200 | 549 |
| Westminster, Colorado | 7,200 | 764,159,300 | 1,348 |
| West Valley City, Utah | 6,200 | 795,258,200 | 1,459 |
| Arvada, Colorado | 4,700 | 504,287,400 | 1,116 |
| West Jordan, Utah | 3,600 | 363,995,000 | 1,376 |

*Land area from TIGER/Line files, National Historical Geographic Information System 2010; population from U.S. Census American Fact Finder.*

## Alternative Fuel Vehicles

Denton had a higher-than-average percentage of registered hybrid electric vehicles in 2013, ranking in the top 14% out of the more than 23,400 cities with vehicle type data analyzed by Cities-LEAP. Light-duty vehicles registered in Denton as of 2013 had an average fuel economy of 23 miles per gallon, placing the city in the top 13% of the cities analyzed.

Flex fuel is the most common type of alternative fuel vehicle (AFV) in Denton at 8% of all registered light-duty vehicles, followed by diesel and biodiesel (3%) and hybrid electric (1%) (Figure 3). Of the approximately 2,300 registered heavy- and medium-duty vehicles in Denton, the SLED 2013 data indicate that none are AFVs. While the number of registered electric vehicles (EVs) in Denton more than tripled between 2013 and 2016, there were fewer than 100 EVs registered as of 2016.

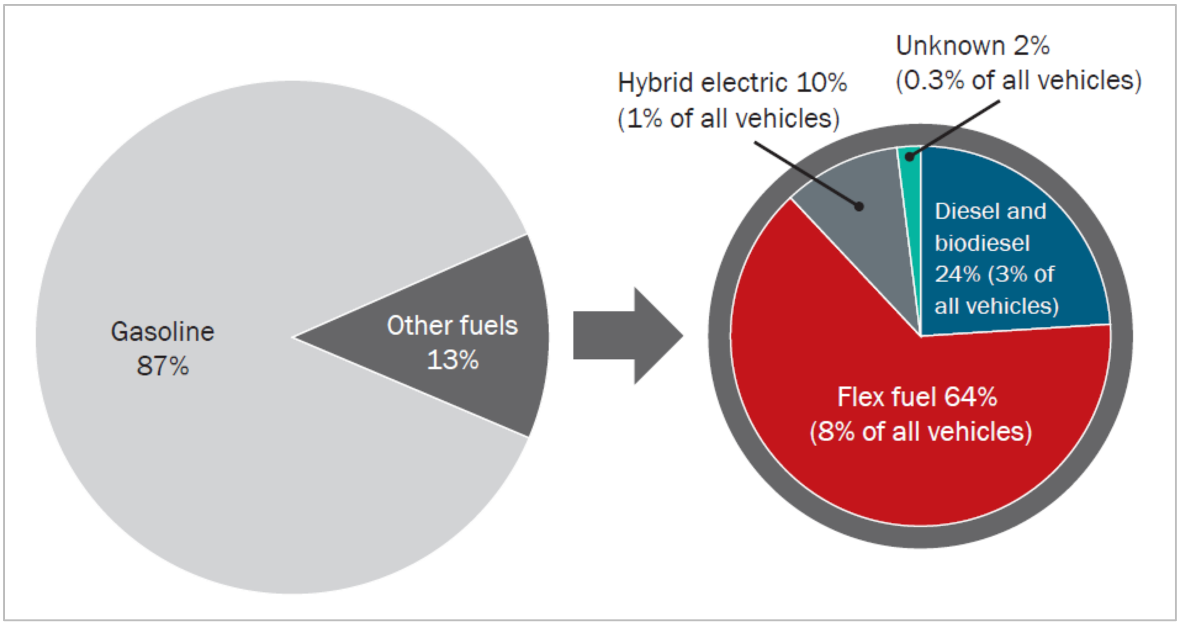



**Figure 3. Light-duty conventional and alternative fuel vehicles by type (2013) registered in Denton, Texas, from SLED**

## Alternative Fueling Stations

According to the DOE Alternative Fueling Station Locator, accessible through the transportation tab of Denton's city energy profile on SLED and at [afdc.energy.gov](afdc.energy.gov), Denton has 16 public alternative fueling stations, including 11 electric (3 of which are for Teslas only), 3 ethanol (E85), and 2 liquefied petroleum gas (LPG). While there is limited information available to determine an ideal ratio of number of EVs to public charging stations, an NREL analysis noted that the average U.S. county hosted approximately 43 public plug-in stations for every 1,000 registered EVs by the end of 2015.[3] In comparison, Denton has more than double this value as of 2016.

[3] E. Wood, S. Raghavan, C. Rames, J. Eichman, and M. Melaina, *Regional Charging Infrastructure for Plug-In Electric Vehicles: A Case Study of Massachusetts*, NREL (2017), http://www.nrel.gov/docs/fy17osti/67436.pdf.

## Strategies for Reducing On-Road Vehicle Fuel Consumption

DOE's Clean Cities program, which leverages nearly 100 local coalitions to reduce petroleum use in transportation, reports that AFVs contributed 87% of the reductions in petroleum consumption from Clean Cities activities in 2015. The remaining savings were from increased fuel economy, reduced vehicle idling, and strategies to lower VMT.[4]

Flex-fuel vehicles, which are optimized to use either E85 (a blend of up to 85% ethanol and 15% gasoline) or regular gasoline, comprise the largest percentage of AFVs in Denton (Figure 3). However, E85 vehicles are more often fueled with regular gasoline.[5] With only three E85 fueling stations in Denton, many flex-fuel vehicles in the city are likely purchased for other attributes and primarily fueled with gasoline.

Among alternative fuel vehicles, Clean Cities reports varying amounts of petroleum saved and greenhouse gas emissions reduced from Clean Cities activities (Figure 4). The significant difference in the amount of petroleum saved across AFV types is attributed to four factors that may be considered when targeting fuel reduction actions:

1. The frequency with which the AFV uses alternative fuel (dedicated AFVs tend to displace more petroleum than flex-fuel vehicles, which can use either gasoline or E85)
2. The annual mileage of the AFV (higher mileage displaces more petroleum)
3. The AFV's fuel economy (vehicles with lower fuel economy—such as waste-hauling vehicles, school buses, and other heavy-duty vehicles— consume more fuel per mile; and switching to alternative fuels displaces more petroleum consumption)
4. The amount of petroleum contained in the alternative fuel (ethanol and biodiesel blends contain significant quantities of petroleum).

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[4] C. Johnson and M. Singer, *Clean Cities 2015 Annual Metrics Report*, NREL (2016), https://www.afdc.energy.gov/uploads/publication/2015_metrics_report.pdf.

[5] S. Pouliot and B. Babcock, "The Demand for E85: Geographical Location and Retail Capacity Constraints," *Science Direct* 45 (September 2014): 134–143.

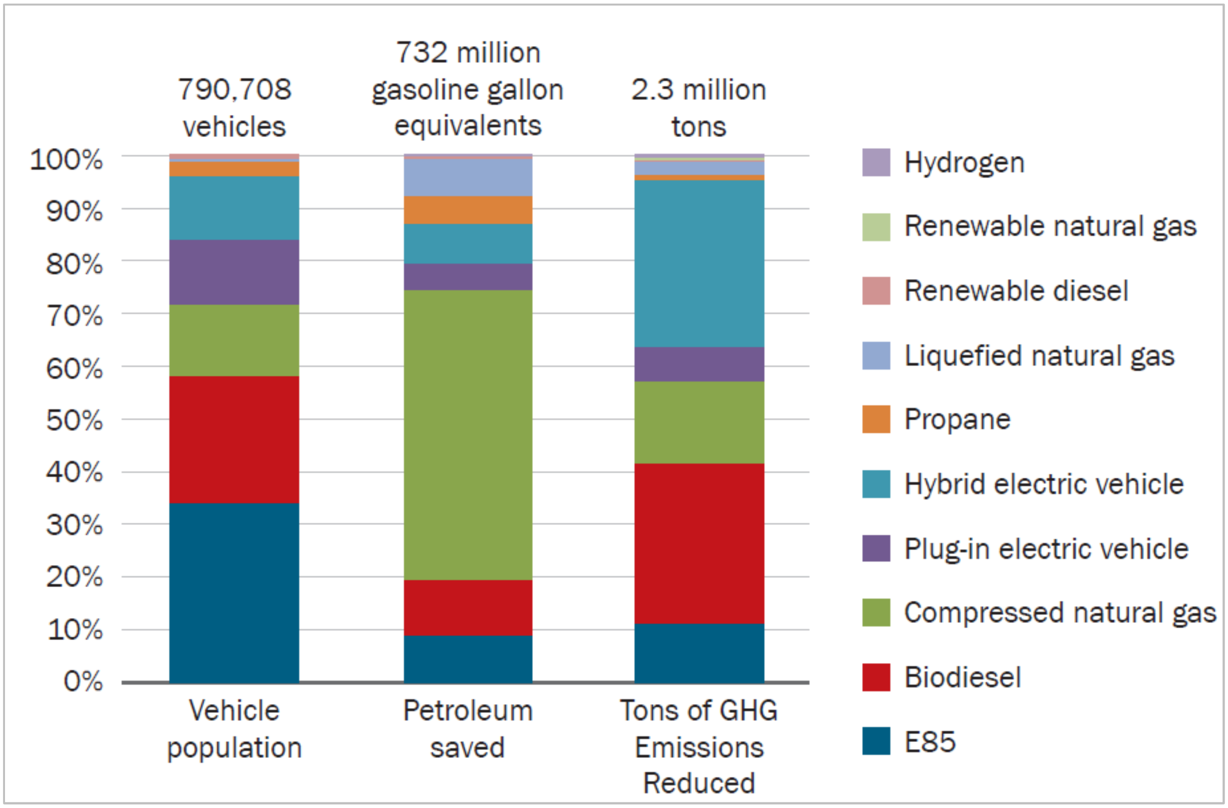


**Figure 4. Percent of AFVs, petroleum savings, and greenhouse gas emissions (GHG) reductions by fuel type reported by Clean Cities coalitions (2015)**

*Source: C. Johnson and M. Singer, Clean Cities 2015 Annual Metrics Report, NREL [2016]*

AFV bulk purchasing programs offer opportunities to collaborate across a region to increase AFV adoption. Fleets for the Future facilitates bulk orders of AFVs with fleet discounts on propane, electric, plug-in hybrid electric, and natural gas vehicles. The Dallas-Fort Worth region[6] and other areas have regional initiatives that officials can contact for assistance.

Strategies to reduce fuel consumption through increased AFV adoption include the following:

- Integrate AFVs into Denton's municipal fleet, and install alternative fueling stations at municipal properties
- Streamline the permitting and inspection of AFV charging installations to reduce costs and development time[7]
- Require EV charging station installation in commercial building codes, as well as development and parking regulations, to integrate EV charging into multifamily buildings and larger workplaces
- Strategically deploy EV charging stations based on dwell time at public locations, trip distances within a single-charge range,[8] and visibility to reduce range anxiety and enable longer electric-only trips
- Provide incentives such as density bonuses and reduced parking requirements for installing EV charging infrastructure in new residential and commercial development[9]

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[6] Fleets for the Future Dallas - Forth Worth region: http://www.fleetsforthefuture.org/dallas-fort-worth.

[7] For more information, see the California Plug-In Electric Vehicle Collaborative, *Streamlining the Permitting and Inspection Process for Plug-In Electric Vehicle Home Charger Installations*: http://pevcollaborative.org/sites/all/themes/pev/files/PEV_Permitting_120827.pdf.

[8] E. Wood, J. Neubauer, and E. Burton, *Measuring the Benefits of Public Chargers and Improving Infrastructure Deployments Using Advanced Simulation Tools*, NREL (2015), http://www.nrel.gov/docs/ fy15osti/63422.pdf.

[9] See AFDC Local Laws and Incentives: https://www.afdc.energy.gov/laws/local_examples.

- Adopt zoning ordinance amendments to enable the installation of EV charging stations and encourage their appropriate placement.

Increased population density is correlated with lower VMT per capita,[10,11] suggesting that land use strategies that support greater density and infill (which in turn, support active transportation options such as walking and biking, and public transit ridership) may help Denton reduce VMT per capita. Of the Clean Cities coalition actions to reduce VMT, mass transit projects were the most effective, followed by carpooling.[12]

## Resources

The following resources may be useful to guide further research and action steps:

### DOE Clean Cities

The Clean Cities program supports local actions to cut petroleum use in transportation. Contact your local coalition for assistance with implementing alternative fuels and advanced vehicle technologies: https://cleancities.energy.gov.

### VMT and Fuel Consumption

- Alternative Fuels Data Center: https://www.afdc.energy.gov/
- Transportation Data Book: http://cta.ornl.gov/data/index.shtml
- U.S. Energy Information Administration—Alternative Fuel Vehicle Data: https://www.eia.gov/renewable/afv/index.php.

Find additional resources in the SLED Local Energy Action Toolbox: https://apps1.eere.energy.gov/sled/cleap.html. Resources include examples and guides to action for incentivizing the adoption of alternative fuels, anti-idling measures, VMT reduction incentives, and fuel switching for municipal fleets.

# 2 Achieving Low-Income Household Energy Savings

With two universities and approximately 40,000 students living in Denton, the city is particularly interested in addressing energy efficiency gaps in multi-family low-income and rental properties. Of the 43,745 occupied housing units in Denton, an estimated 52.3% are renter-occupied, which is higher than both the statewide (37.8%) and national (36.1%) averages of renter-occupied units (Table 3).[13]

**Table 3. Share of Housing Units by Ownership Status in Denton, TX Compared to State and U.S. Averages**

| | Denton, TX | Texas | United States |
|---|---|---|---|
| Renter-Occupied | 52.3% | 37.8% | 36.1% |
| Owner-Occupied | 47.7% | 62.2% | 63.9% |

*Source: U.S. Census Bureau, 2011-2015 American Community Survey*

[10] *The Planning Perspective on Health: Community Health as a Goal of Good Design*, ChangeLab Solutions (2007), http://changelabsolutions.org/sites/default/files/documents/Factsheet_PlanningPerspective.pdf.
[11] *Our Built and Natural Environments: A Technical Review of the Interactions Among Land Use, Transportation, and Environmental Quality*, U.S. Environmental Protection Agency (2013), http://contextsensitivesolutions.org/content/reading/built-and-natural.
[12] C. Johnson and M. Singer, *Clean Cities 2015 Annual Metrics Report*, NREL (2016), https://www.afdc.energy.gov/uploads/publication/2015_metrics_report.pdf.
[13] U.S. Census Bureau. American Fact Finder. Selected Housing Characteristics, 2011-2015 American Community Survey 5-Year Estimates.

The U.S. Department of Housing and Urban Development (HUD) determines low-income status as a percentage of area median income (AMI) for a given location. HUD defines very low-income as households earning 50% or less of AMI.[14] Based on an analysis of HUD and U.S. Census data,[15] 48% of renter-occupied units in Denton qualify as very low-income households, compared to fewer than 12% of owner-occupied units (Figure 5). Renters in Denton are more likely to fall into lower income brackets than their homeowner counterparts.

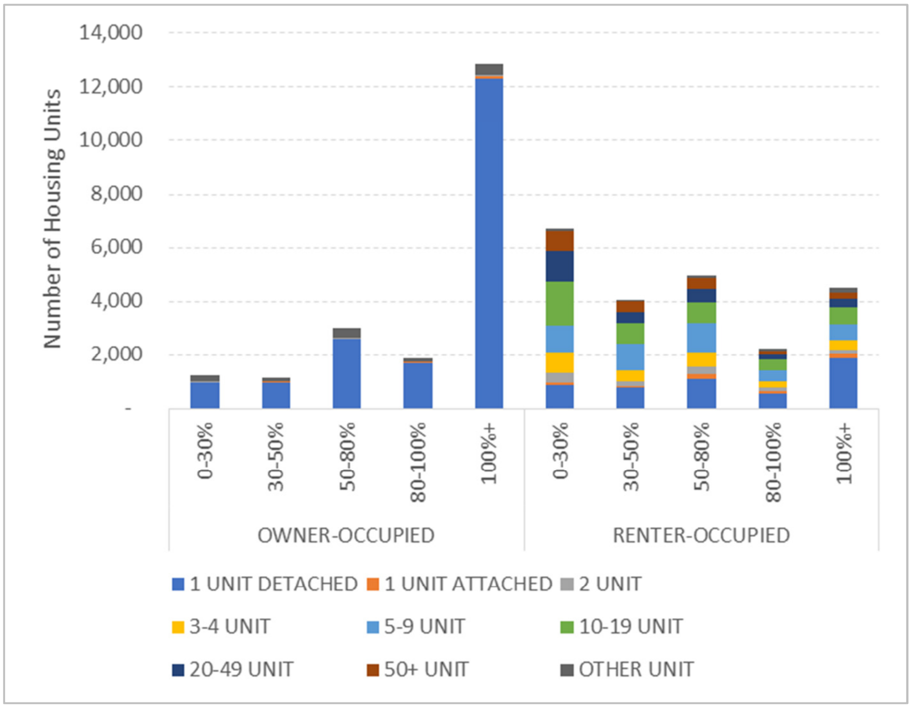


**Figure 5. Number of Housing Units by Housing Type and Area Median Income in Denton, TX[16]**

Renters in Denton are also likely to live in multi-family buildings: 67% of all renter-occupied units are in buildings of three or more units (Figure 6).

[14] State and county-level income limits are updated every fiscal year and are based on the number of people per household. Income limit documentation is available at https://www.huduser.gov/portal/datasets/il.html.

[15] See Appendix A for methodology behind the low-income data analysis.

[16] The data, results, and interpretations presented in this analysis have not yet been reviewed by technical experts outside NREL, the U.S. Department of Energy, or the City of Denton.


**Figure 6. Total Number of Housing Units by Housing Type and Ownership Status**[17]

Energy burden, the ratio of energy expenditures to household income, is a metric commonly used to evaluate the relative cost burden of energy expenditures on households. Renter-occupied households have lower energy burdens than owner-occupied households in corresponding AMI categories in Denton (Figure 7).

[17] The data, results, and interpretations presented in this analysis have not yet been reviewed by technical experts outside NREL, the U.S. Department of Energy, or the City of Denton.

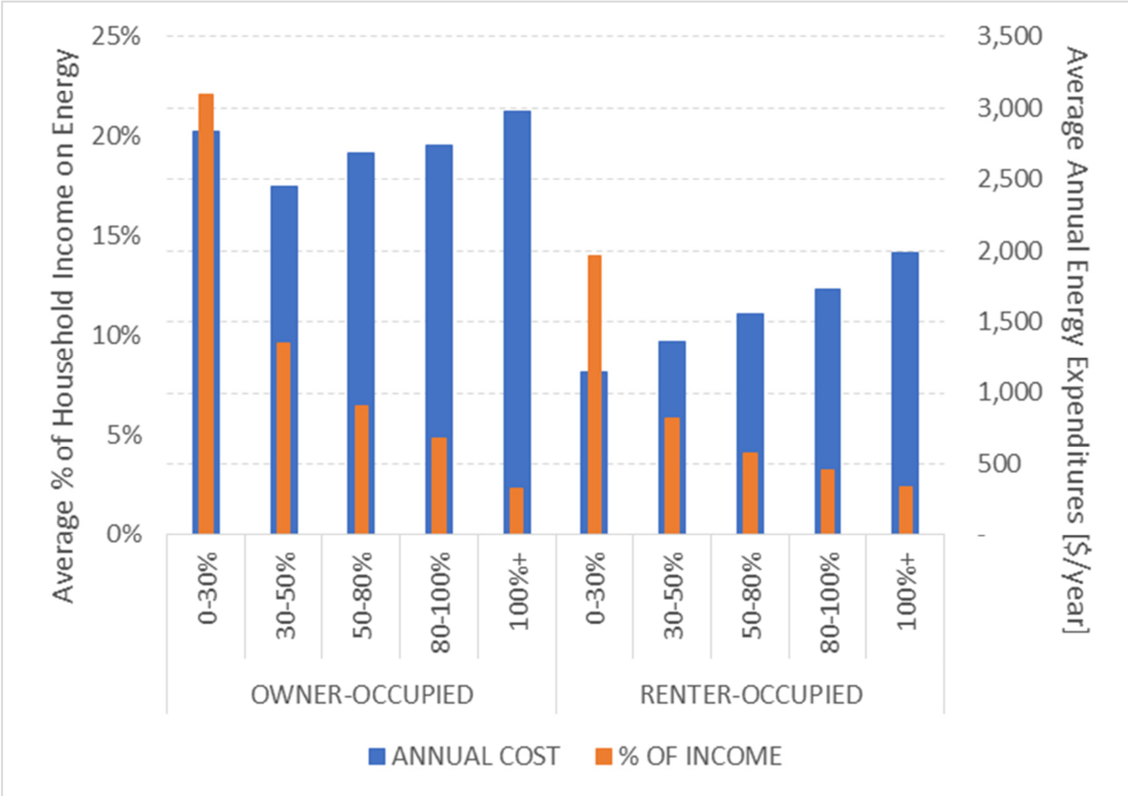


**Figure 7. Energy Burden (Average Energy Expenditures/Average Income, $/Year) for Denton, TX[18]**

Renter households across all AMI categories in Denton, and most communities, have lower total annual energy costs than owner-occupied households. This situation may correlate with factors such as differences in unit area and household size, as well as shared walls and rental units that do not have separately metered utilities.

An estimated 76% of rental units in Denton are electrically heated compared to approximately 37% of owner-occupied units (see Figure 8). The slightly lower energy burden among renters may also be correlated with the increased likelihood that rental units are electrically heated, as average monthly expenditures on electricity are lower than other forms of heating in Denton (see Figure 9).

[18] The data, results, and interpretations presented in this analysis have not yet been reviewed by technical experts outside NREL, the U.S. Department of Energy, or the City of Denton.

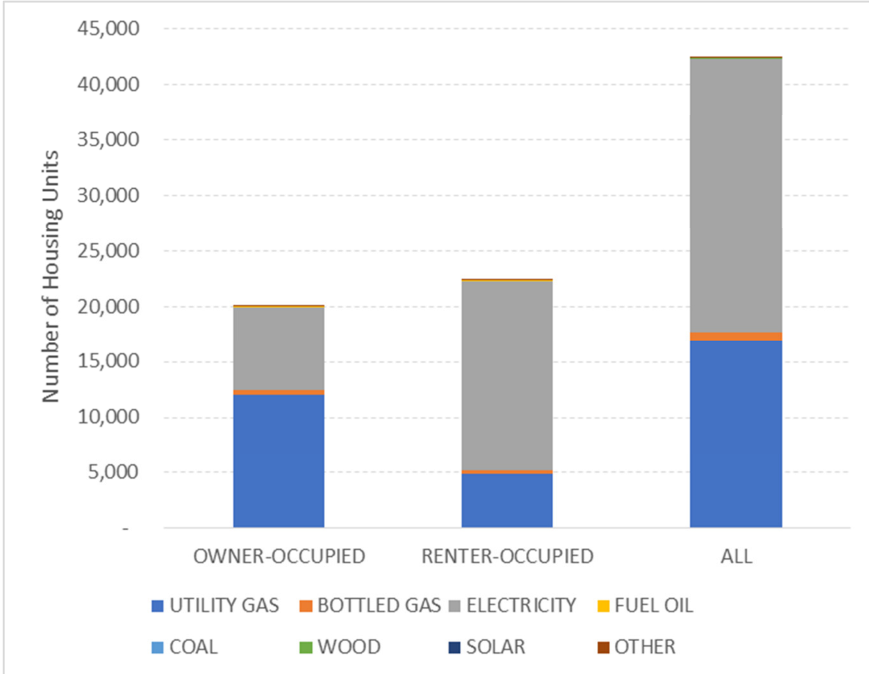


**Figure 8. Number of Housing Units by Heating Fuel Type and Ownership Status in Denton, TX[19]**

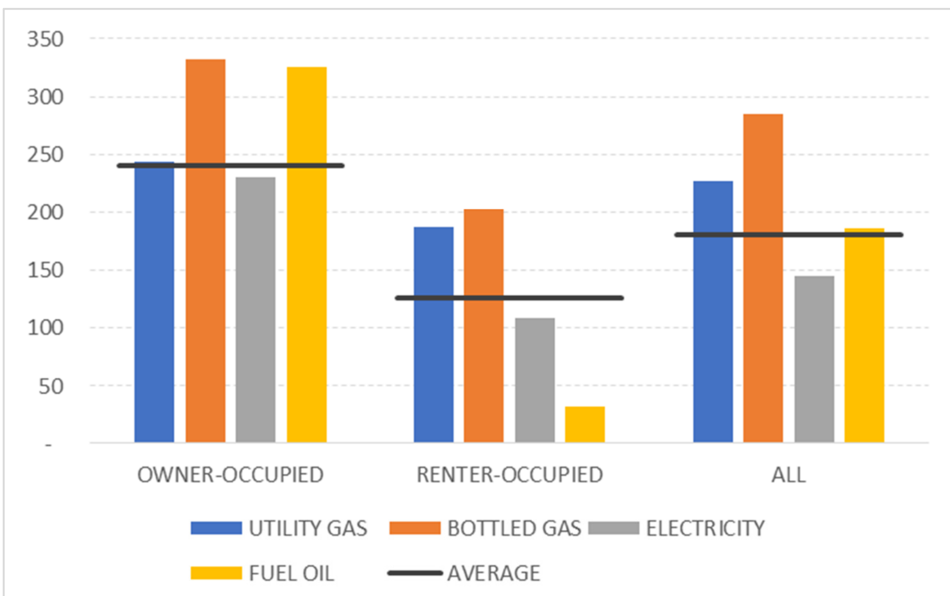


**Figure 9. Average Monthly Expenditures ($/Month) by Heating Fuel Type in Denton, TX[20]**

[19] The data, results, and interpretations presented in this analysis have not yet been reviewed by technical experts outside NREL, the U.S. Department of Energy, or the City of Denton.
[20] The data, results, and interpretations presented in this analysis have not yet been reviewed by technical experts outside NREL, the U.S. Department of Energy, or the City of Denton.

An analysis of potential energy cost savings in single-family detached homes in each state, based on a detailed modeling of 350,000 representative individual houses, found that the following are the most cost effective measures in Texas (Figure 10), which may be mirrored at the city-level:

1. Installing smart thermostats
2. Upgrading to ENERGY STAR® refrigerators
3. Upgrading to ENERGY STAR® clothes washers
4. Adding wall insulation
5. Replacing electric furnaces with variable-speed heat pumps at wear out.

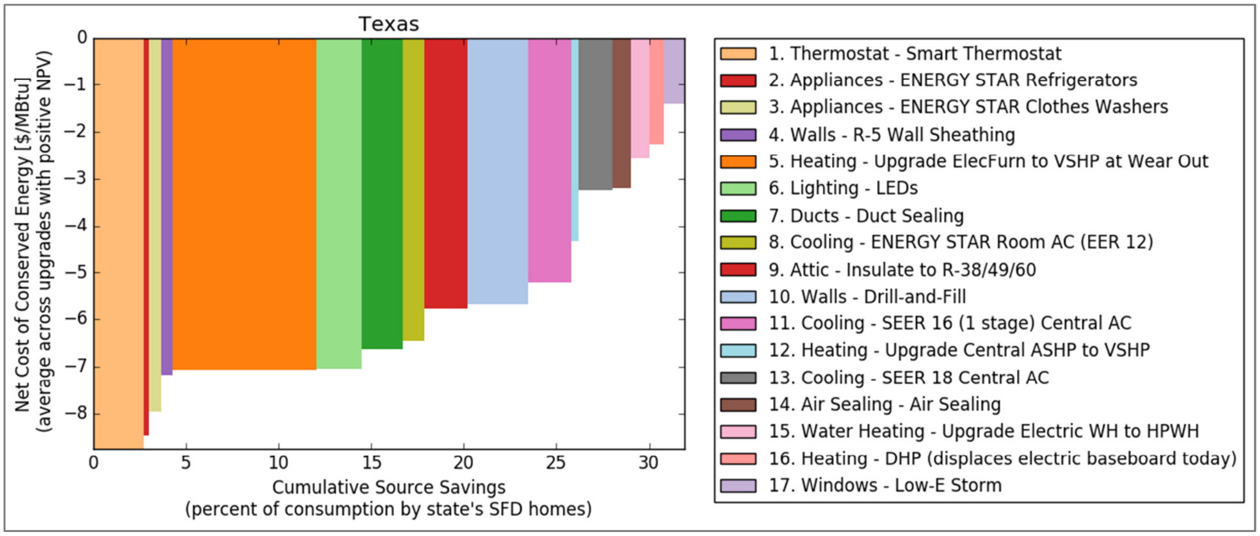


**Figure 10. Energy efficiency supply curve for Texas**

*Data from the NREL analysis of possible electricity cost savings (https://www.nrel.gov/docs/fy17osti/65667.pdf)*

*(NPV = net present value; VSHP = variable-speed heat pump; ASHP = air-source heat pump; WH = water heater; HPWH = heat pump water heater.)*

## Approaches to Reducing Energy Burden and Increasing Energy Efficiency

In Denton, programs that target energy efficiency upgrades in multi-family buildings may have a greater impact on the low-income population. Additionally, because rental units in Denton are already more likely to use electricity as a heating source, and because average monthly electricity expenditures are low relative to other heating fuels, converting rental properties from utility gas heating to electric, variable-speed heat pumps may target units with occupants that experience a higher energy burden.

Additional measures to increase the efficiency of low-income and rental properties include the following:

- Time-of-sale efficiency requirements
- Rental and low-income weatherization programs
- Mechanisms to disclose anticipated utility bills to potential renters and buyers
- Requiring renovations to meet building energy codes
- Improving building energy code compliance rates

- Adopting beyond-code measures (i.e., city policies that go beyond state-level or the latest vintage of building codes, such as the International Energy Conservation Code[21])
- Requiring new multi-family developments to meet efficiency standards in order to receive zoning and development approvals.

## Resources

The following resources may be useful to guide further research and actions:

### *SLED Local Energy Toolbox*

Find a catalogued, searchable list of more than 500 resources: https://apps1.eere.energy.gov/sled/cleap.html

### *Rental Property Energy Efficiency Policy Case Studies*

*Vermont*

- Burlington, Vermont's Time of Sale Energy Efficiency Ordinance requires certain energy efficiency upgrades at the time of property sale for rental properties where tenants are responsible for heating costs.
- More information: https://www.burlingtonelectric.com/sites/default/files/Documents/Energy_Eff/time-of-sale-energy-ordinance.pdf

*Wisconsin*

- The state's Rental Weatherization Program requires energy efficiency upgrades at the time of property transfer for certain classes of rental units.
- More information: http://www.dsps.wi.gov/Programs/Industry-Services/Industry-Services-Programs/Rental-Weatherization and http://dsps.wi.gov/sb/docs/SB-RentalWeatherizationBrochure7366.pdf

*Maine*

- Landlords are required to disclose energy aspects of a property that may impact energy consumption at the location.
- More information: http://www.maine.gov/mpuc/online/forms/EnergyEfficiencyDisclosure.html

### *Low-Income Energy Efficiency Resources*

*Residential*

- Better Buildings Low Income Accelerator: https://betterbuildingsinitiative.energy.gov/accelerators/clean-energy-low-income-communities
- Energy Efficiency in Affordable Housing, an EPA guide for local governments https://www.epa.gov/statelocalclimate/energy-efficiency-affordable-housing
- Oregon state energy efficiency appliance rebate program helps low-income families http://energy.gov/eere/success-stories/articles/eere-success-story-oregon-state-energy-efficiency-appliance-rebate
- RentRocket.org is a rental housing search pilot-project in several college towns aimed at compiling information on factors like utility costs and access to public transportation to help renters make more informed housing decisions. Cities currently partnering on the project include Albany, NY; Ann Arbor, MI; Berkeley, CA; Bloomington, IN; Burlington, VT; Columbia, MO; Dearborn, MI; Evanston, IL; Iowa City, IA; Madison, WI; and San Antonio, TX.
- Renters guide for energy efficiency (includes strategies, a checklist for what to ask for when renting a property, and additional resources): http://www.ct.gov/deep/lib/deep/energy/a_renters_guides_to_energy_efficiency.pdf

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[21] International Energy Conservation Code Resource Page, International Code Council, https://www.iccsafe.org/about-icc/government-relations/international-energy-conservation-code-resource-page/.

*Multifamily*

- Energy Efficiency for All: Making Multifamily Homes Healthy and Affordable: http://energyefficiencyforall.org/issues/program-design-and-budgets

*Renter-Owner Split Incentives*

- Policy options for the split incentive: Increasing energy efficiency for low-income renters (Energy Policy Journal): http://www.sciencedirect.com/science/article/pii/S0301421512004661
- Report from the Rental Housing Energy Efficiency Work Group in Minnesota: http://www.sciencedirect.com/science/article/pii/S0301421512004661
- Case Study on Boulder, Colorado's Rental Housing Policy: http://aceee.org/files/proceedings/2012/data/papers/0193-000251.pdf

# Appendix A. Transportation Data Methodologies

Data and methodologies for information presented on the SLED website are provided on the SLED website. In the city energy profile, click on the "Data Methodology" or "Download Data" buttons to read more.

## *Vehicle Miles Traveled:*

*Methodology*

The data for aggregate 2013 vehicle miles traveled (VMT) were derived by the National Renewable Energy Laboratory (NREL) using two datasets: the Federal Highway Administration (FHWA) Highway Performance Monitoring System (HPMS) Shapefiles (FHWA 2013a) and FHWA Highway Statistics Series Table VM-2 (FHWA 2013b). The HPMS Shapefiles are comprised of geo-located road segments for the entire U.S. and attributed with road class information and measured or estimated annual VMT. While these data are rich in spatial detail, they are often incomplete in attribution, for example, omitting VMT for minor road classes. As a result, they do not necessarily sum to the state level VMT totals given in Tables VM-2. To ensure a complete accounting of the state level VMT totals, we used Table VM-2 to backfill missing VMT data in the HPMS shapefiles, calibrating the results to ensure the road segment VMT totals and VM-2 totals were consistent by road class and in aggregate at the state level.

*References Cited*

FHWA. (2013a). HPMS Public Release of Geospatial Data in Shapefile Format, 2013. Available online: https://www.fhwa.dot.gov/policyinformation/hpms/shapefiles.cfm. Accessed 7/15/2015.

FHWA (2013b). Highway Statistics Series 2013. Available online: http://www.fhwa.dot.gov/policyinformation/statistics/2013/. Accessed 7/15/2015.

## *On-Road Vehicle Fuel Consumption*

*Methodology*: The data for aggregate 2013 vehicle fuel consumption for cities and towns in SLED were derived through an analytical process performed by the National Renewable Energy Laboratory (NREL). This process estimated fuel consumption by integrating publicly and commercially available datasets at various spatial resolutions describing traffic intensity, vehicle fuel economy, and regional fuel consumption totals. Table A-1 below outlines the source and characteristics of datasets used by NREL. The analysis methods are summarized in Figure A-1 and described in more detail at the following link: https://widgets.nrel.gov/mea/commre/assets/fuel_use_analysis.pdf.

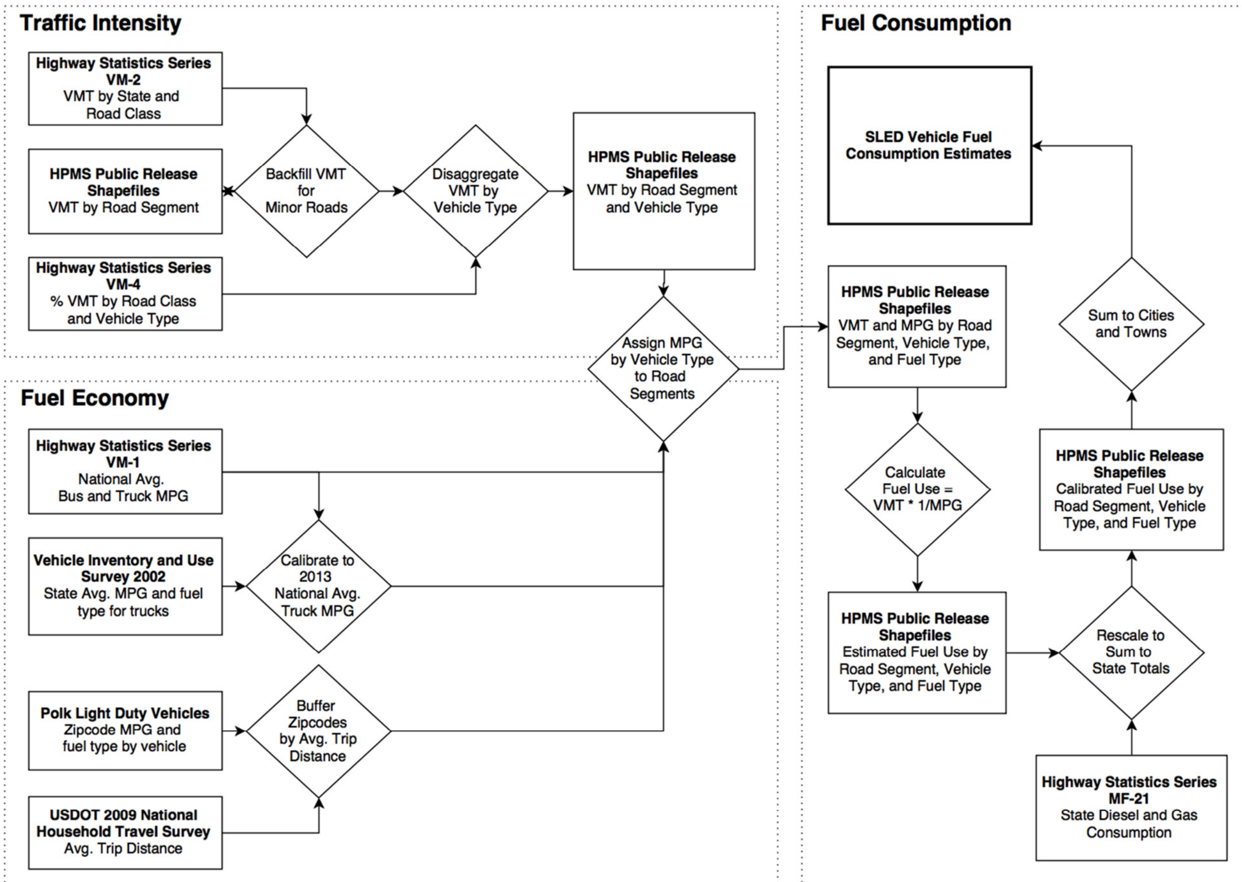


**Figure A-1: Summary of on-road vehicle fuel consumption methods.**

## *Table A-1. Cities-LEAP On-Road Vehicle Fuel Consumption Data Sources*

| Data Category | Dataset | Spatial Resolution | Measures | Use | Source | Vintage | Publicly Available |
|---|---|---|---|---|---|---|---|
| Traffic Intensity | Highway Performance Monitoring System (HPMS) Public Release Shapefiles | Individual Local Road Segments | Vehicle Miles Traveled (VMT)<br>Rural/Urban<br>Road Class (7 types)<br>State | Provides estimate of intensity of local traffic intensity at a highly granular spatial resolution. Combined with other ancillary traffic intensity and mpg data to derive local estimates of fuel consumption. | FHWA Highway Performance Monitoring System | 2013 | Yes |
| Traffic Intensity | Highway Statistics Series VM-2: Vehicle-miles of travel, by functional system | States | Total Vehicle Miles Traveled<br>Rural/Urban<br>Road Class (7 types) | Accounts for best and most highly resolved estimate of total VMT by urban/rural and road class in each state. Used to calibrate and backfill missing data in HPMS Public Release Shapefiles. | FHWA Highway Statistics Series | 2013 | Yes |
| Traffic Intensity | Highway Statistics Series VM-4: Distribution of Annual Vehicle Distance Traveled | States | Percent of VMT<br>Rural/Urban<br>Generalized Road Class (3 types)<br>Vehicle Type (6 types) | Accounts for best and most highly resolved estimate of total VMT by urban/rural, generalized road class, and vehicle type in each state. Used to disaggregate VMT proportions by vehicle type along HPMS Public Release Shapefiles. | FHWA Highway Statistics Series | 2013 | Yes |
| Fuel Economy | Vehicle Inventory and Use Survey Microdata | States | Vehicle type (2 types)<br>Fuel economy (mpg) | Best and highest resolution publicly available estimate of average mpg for single-unit and combination trucks. Used to derive regional estimates of average mpg by vehicle type for these two truck classes. | US Census Bureau | 2002 | Yes |
| Fuel Economy | Highway Statistics Series VM-1: Vehicle miles of travel and related data, by highway category and vehicle type | Nation | Vehicle type (6 types)<br>Fuel economy (mpg) | Used as the best available estimate of fuel economy for buses. Also used to calibrate Vehicle Use and Inventory Survey truck mpg data to ensure consistency with national average from 2013. | FHWA Highway Statistics Series | 2013 | Yes |
| Fuel Economy | Polk Counts of Light Duty Vehicle Registrations | Zip Codes | Vehicle type (6 types)<br>Fuel economy (mpg)<br>Fleet type (personal, dealer, etc.) | High resolution estimate of average mpg for locally registered vehicles. Used to derive local estimates of average mpg by vehicle type for light duty vehicles (passenger cars and light trucks). | RL Polk & Company | 2013 | No |
| Fuel Economy | USDOT 2009 National Household Travel Survey | Census Tracts | Average Trip Distance (mi)<br>Urban/Rural | Aggregated to state averages for urban/rural. Applied to Polk Light Duty Vehicles to determine an average range of travel beyond zipcode of registration, allowing for assignment to individual HPMS road segments. | USDOT Bureau of Transportation Statistics | 2009 | Yes |
| Fuel Consumption | Highway Statistics Series MF-21: Motor Fuel Use | States | Vehicle Fuel Consumption (gallons)<br>Fuel type (gas/diesel) | Best and most highly resolved reporting of annual fuel consumption (gas and diesel) by state. Used to determine final estimate of fuel consumption along HPMS road segments by disaggregating proportional to their derived estimates of fuel consumption. This ensures that state totals from MF-21 are maintained in the final fuel estimates. | FHWA Highway Statistics Series | 2013 | Yes |

# Appendix B. Low-Income Data Analysis Methodology

This is a preliminary draft methodology. Methodology is currently under review.

## *Residential Household Disaggregation and Energy Expenditures*

**Overview**
This work derives a number of cross-tabulations of US Census housing data at the Census Tract level. Estimates include the number of occupied housing units and their average household energy expenditures by housing unit building year of first construction, number of units, the primary heating fuel type, the household area median income bin, and tenure (i.e., whether the housing unit is owner occupied or renter occupied).

**Data Sources**
2015 5-Year American Community Public Use Microdata Samples (US Census)
2015 5-Year American Community Survey published tables (US Census):
- B25118: Household income by tenure
- B25036: Building year of first construction by tenure
- B25127: Building year of first construction by number of units in building by tenure
- B25032: Number of units in building by tenure
- B25117: Primary heating fuel type by tenure
- B25124: Number of persons by number of units in building by tenure
- B25009: Number of persons by tenure

FY2015 Fair Market Rent and Income Limits (US HUD)
2015 EIA-861
2015 EIA-176

**Methodology (Housing Unit Counts)**
Estimates of housing units rely on the use of an Iterative Proportional Fitting (IPF) algorithm (Lovelace, 2014; Pritchard & Miller, 2012). IPF is used sequentially to build increasingly complex cross-tabulations. Published tables from the American Community Survey (ACS) are used as constraints in the IPF algorithm and derived tables from the ACS Public Use Microdata Samples (PUMS) are used as initial guesses for the cross tabulations of those constraints. This is done for each Census Tract with the corresponding Public Use Microdata Area (PUMA) for the initial guess.

The sequence is as follows:
1. A cross tabulation of B25009 (number of persons by tenure) by B25124 (number of persons by units in building by tenure) is developed first to increase the resolution of B25124 from 1-5 persons to 1-7 persons.
2. A cross tabulation of the prior result by B25032 (number of units in building by tenure) is developed to then increase the resolution of B25124 from 6 to 10 different categories.
3. A final cross tabulation is then developed for this prior result by B25118 (household income by tenure) and B25117 (primary heating fuel type by tenure) with summations over redundant axes.
4. This final result is rearranged so that one axis is B25009 (number of persons by tenure) by B25118 (household income by tenure). This is necessary for placing housing units in different area median income bins as discussed below.

**Methodology (Energy Expenditures)**
Estimates of household energy expenditures are derived by using the same cross tabulations as for the housing unit counts from the ACS PUMS for each PUMA. These cross tabulations are simple weighted averages of the sample data. For the 2015 5-year ACS PUMS data, only 4 years can be used since the 2011 survey uses the older 2000 PUMA definitions.

The ACS PUMS surveys three categories of household energy expenditures: electricity, gas, and other fuel types. They also include flags for households who include any of those costs in other housing costs such as rent and for households who have only a single bill for electricity and gas. There is no differentiation of utility gas (typically natural gas) and bottled gas (typically propane) expenditures. There is also no differentiation in the various other fuel types, which can include fuel oil, kerosene, coal, wood, and solar energy. Electricity and gas expenditures are based on the month prior to the survey. Other fuel expenditures are based on the 12-months prior to the survey.

This approach has a number of shortcomings aside from typical issues with sample data and the lack of geographic specificity. Since electricity and gas expenditures are taken for a single month, and that month is not specified, one cannot assess how well the sample is representative of all months of the year. Also, combined electricity and natural gas bills are placed in the electricity expenditures category, overestimating electricity expenditures and underestimating gas expenditures. Further, energy expenditures embedded in other housing costs are set to zero, underestimating the true energy expenditures. Lastly, having utility gas and bottled gas in a single category, one cannot independently verify total utility gas expenditures based on utility reported revenues.

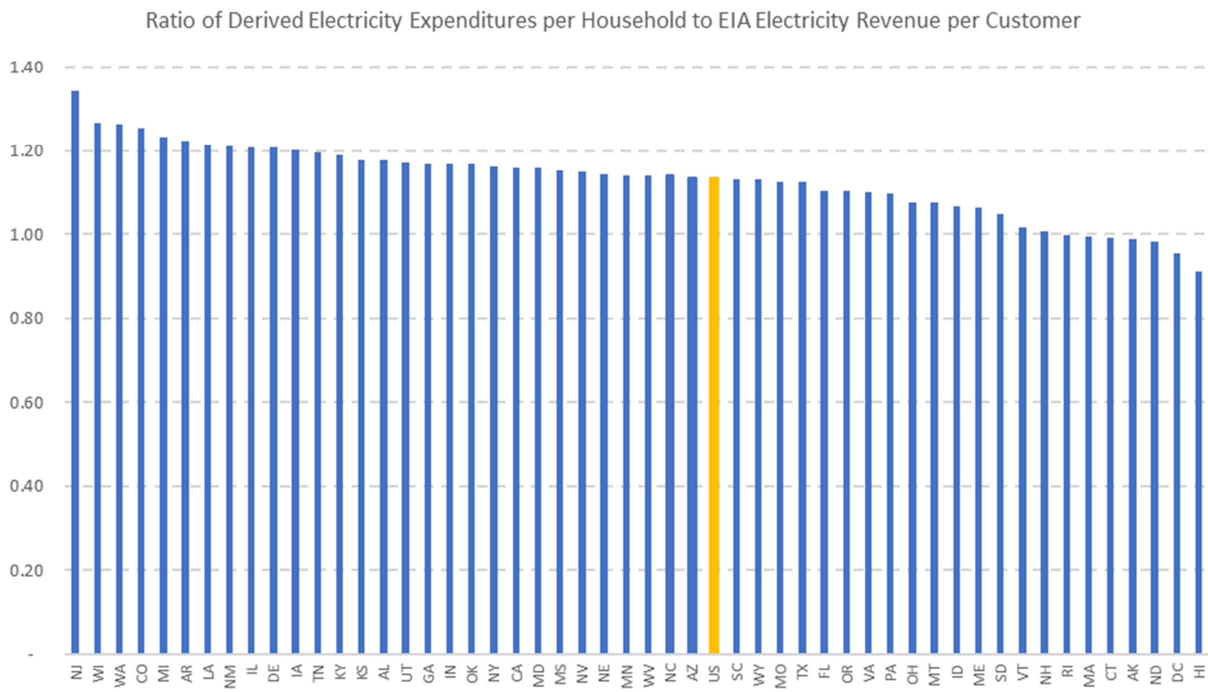


**Figure B-1: State average electricity expenditures per household derived from the Census ACS compared with EIA-861 reported electric utility revenues per residential customer.**

Total state wide electricity expenditures per housing unit are compared to EIA reported electric utility revenue per residential customer, and state-wide gas expenditures per housing unit for those housing units using utility gas as the primary heating fuel type are compared to EIA reported natural gas utility revenue per residential customer. Direct use of this validation data is complicated by two factors. First, utility data includes both occupied and unoccupied housing units, and the ACS PUMS provides information on only the former and not the latter (roughly 12% of housing units are unoccupied). Second, not all natural gas utility customers use natural gas as their primary heating fuel (though generally greater than 80% and even higher for cold climate states). Statewide comparisons show that for most states the derived electricity expenditures fall within 1 and 1.2 times EIA values (Figure B-1) and the derived natural gas expenditures fall within 0.8 and 1.2 times EIA values (Figure B-2).

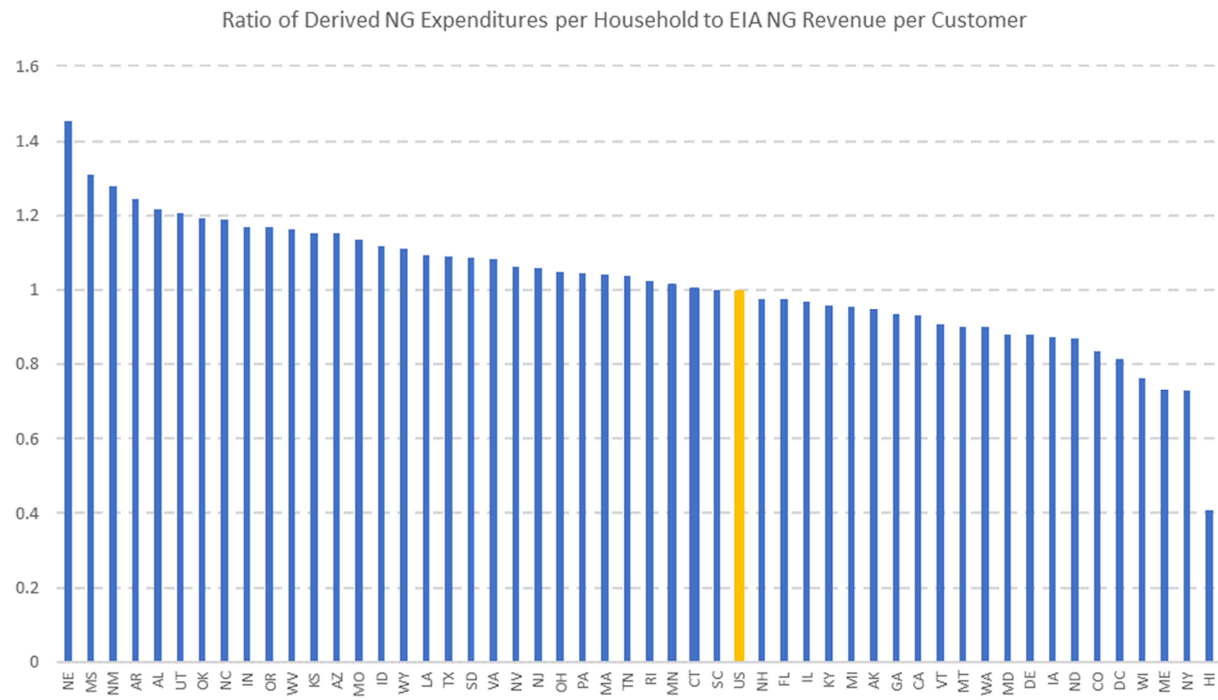


**Figure B-2: State average gas expenditures per household (for households reporting utility gas as the primary heating fuel) derived from the Census ACS compared with EIA-176 reported natural gas utility revenues per residential customer.**

For electricity expenditures, we develop county-level adjustment factors. Utility customers are allocated to each county using the IPF algorithm constrained with total electric residential customers by utility and total occupied households by county. The initial guess is a matrix of one's and zero's based on the Cities-LEAP mapping of utility service territories to counties. The resulting customer-utility allocation is used to take weighted averages of the residential revenues per customer for all counties. In a few cases, there are no utilities mapped to a particular county; and in those cases, the state averages are used instead. Unoccupied housing units are assumed to spend 50% of the electricity bill of an occupied housing unit. The final adjustment factors (e.g., the ratio of county level estimates to the prior Census Tract level estimates) are shown in Figure B-3, sorted from large to small.

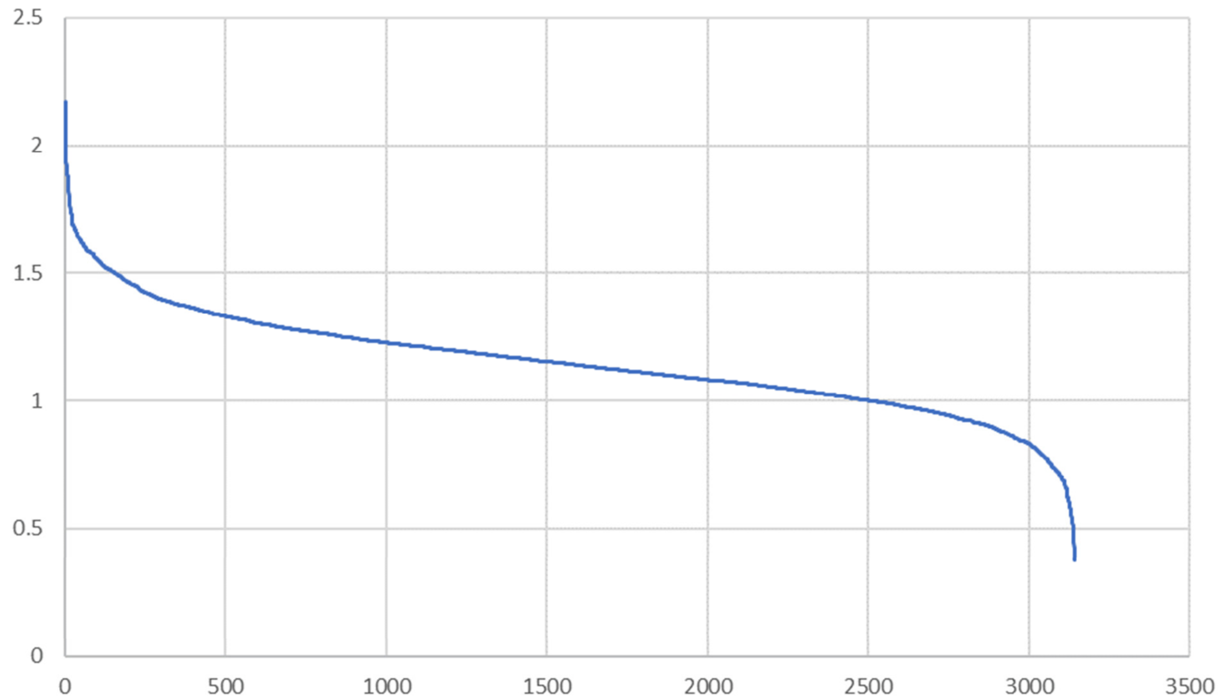


**Figure B-3: County adjustment factors for electricity expenditures. Each point corresponds to a county on the y-axis. Values are sorted from largest to smallest.**

**Methodology (Area Median Income)**
The US Department of Housing and Urban Development (HUD) defines area median income (AMI) based on fair market rent (FMR) areas. For the most part, FMR areas align with towns in New England states and counties in other states. For each FMR area, HUD publishes AMI bins including 30%, 50%, and 80% limits. These AMI limits depend on the size of the household as households with more persons have higher income limits. An additional limit of 100% is extrapolated from the published 80% value by simply dividing by 0.8.

The ACS publishes income bins ranging from $0-5K, $5-10K, and $10-15K through $150K and over. In order to allocate households to different AMI bins, a simple linear weighting is used. For instance, if the 30% AMI limit is $12K, then all of the $0-5K and $5-10K households would be in the 0-30% AMI bin, but only 2/5 of the $10-15K households would be in that bin and the remaining 3/5 would be in the next higher bin of 30-50% AMI. In the ACS data, households include 1-6 persons and 7 or more persons. In the HUD data, AMI limits include 1-7 persons and 8 or more persons. Thus, the 8-person AMI limits are not used in this analysis.

**Methodology (Geographies)**
There are various geographies across data sets. The housing unit counts are at the Census Tract level. The energy expenditures data is at the PUMA level. Finally, the AMI limits are at the fair market rent (FMR) areas. For the 2010 Census and ACS PUMS data beginning with the 2012 survey, PUMA boundaries correspond with counties. Since Census Tracts and counties are part of the primary Census geographic hierarchy, each Census Tract can be assigned a PUMA. Outside of New England, FMR areas align with counties. Thus, as with PUMAs, each Census Tract can be assigned an FMR area. However, in New England, FMR areas align with county subdivisions, which are not part of the primary Census geographic hierarchy. The only common geographic unit between Census Tracts and County Subdivisions is the Census Block. For Census Tracts that fall into two different County Subdivisions, the contained housing units are simply split proportionally with respect to housing unit counts from the 2010 Census.

**References Cited**

Lovelace, R. (2014). Introducing spatial microsimulation with R: a practical. National Center for Research Methods Working Paper. http://eprints.ncrm.ac.uk/3348/4/spat_microsimulation_R.pdf

Pritchard, D. R., & Miller, E. J. (2012). Advances in population synthesis: fitting many attributes per agent and fitting to household and person margins simultaneously. *Transportation, 39*(3), 685---704.