The Balance of Opportunities between Technology Efficiency and Location Efficiency for U.S. Household Energy Savings

Eric Mackres, American Council for an Energy-Efficient Economy

ABSTRACT

Location efficiency—reductions in energy use from choices made about land use and the location and configuration of the built environment—is an underutilized energy efficiency strategy. This paper describes the opportunity for energy savings in buildings and transportation from location efficiency, compares different approaches for determining efficiency potential from location efficiency strategies, and determines the national energy savings contribution of location efficiency in comparison to technology efficiency under forecasted market conditions to 2030. The paper concludes by discussing factors impacting the implementation of location efficiency under real-world conditions and with a state-by-state comparison of transportation energy savings opportunities from location efficiency.

Location Efficiency as Energy Efficiency

Choices made about land use and the location and configuration of the built environment have great influence on the use of energy in buildings and transportation. Land use development choices that result in lower energy consumption are referred to as "location efficiency." This family of efficiency strategies can impact both building and transportation energy use and include what are commonly referred to as "smart growth" and "compact development" that emphasize the connection between where we develop and the availability of housing, employment, and transportation choices.

Location efficiency strategies are energy efficiency strategies. However, rather than being comprised primarily of technology adoption, as is typically associated with energy efficiency, implementation of location efficiency is about understanding neighborhoods and human settlements as energy systems and improving their performance. This systems approach has parallels in many other energy efficiency strategies, including industrial energy management processes and buildings science, which focus on improving the interactions of components rather than just the performance of components themselves. In this paper, I make a distinction between location and technology efficiency. Technology efficiency, for the purpose of this paper, is defined as the improved energy efficiency of a component of a *neighborhood* system (such as a vehicle or home) even if improvements to that component are themselves addressed from a system perspective.

Mechanisms of Location Efficiency

Building configuration, including types and relative orientation, influences energy use because of the insulating effects of shared walls and the amount of conditioned space per person, among other factors. As a result, attached housing types use less energy on average than detached housing: on average, U.S. multifamily homes in buildings of five or more units use only half the energy of single-family detached homes (EIA 2009).

Frequency and distance of personal vehicle travel, large factors in transportation energy use, are heavily influenced by land use and the built environment. In communities where choices other than vehicle travel (i.e., walking, biking, and transit) are available and convenient for everyday trips, they are used. For example, in the San Francisco Bay Area, of people whose home and place of employment are both within a half mile of a rail or ferry transit stop, 42% use a transit method for their commute. The number falls to 4% for people who do not live and work within a half mile (MTC 2006). As a result of these behavioral patterns (and resulting reduced vehicle ownership, vehicle travel, and energy consumption) and other co-benefits, "transit-oriented development" (TOD)—making housing and employment easily accessible to transit—has become a popular location efficiency strategy.

Similar relationships have been found between personal vehicle travel and other land use variables. Scholars have described these land use variables as the "Five D's." Decades of research have established the relationship between these individual variables and the range of reduction in vehicle miles traveled (VMT) that can be gained at the neighborhood or regional scale in a shift from conventional suburban development (Ewing et al. 2008):

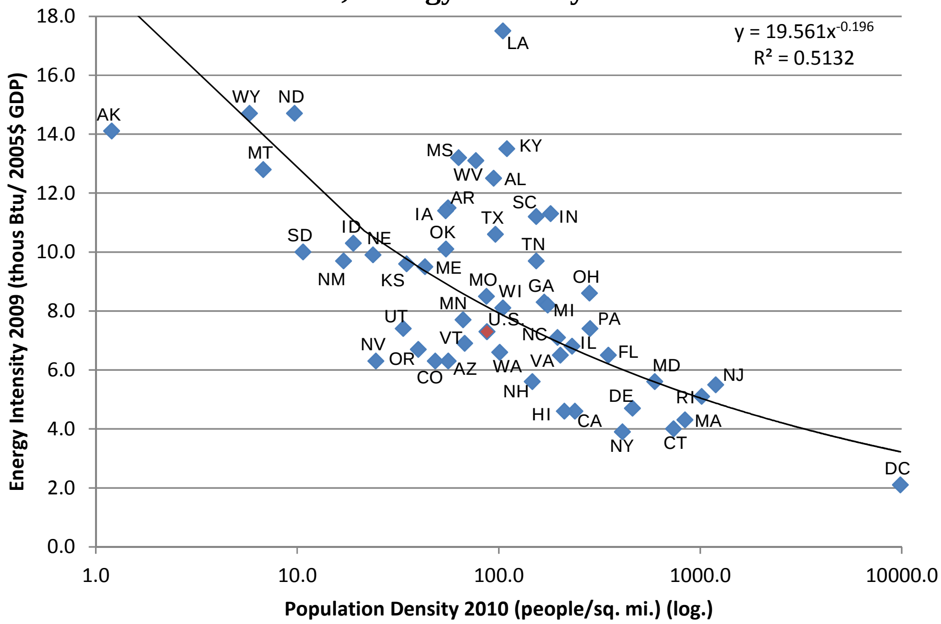
- *Design* (2-20% decrease in VMT)—best practices include street networks with small blocks and many intersections, street widths, sidewalks, building setbacks, street trees, and street crossings that make the area more accommodating to pedestrians and bicycles.
- *Diversity* (20% or more)—best practices include mixed-use neighborhoods with many different land-uses located a short distance from each other, including retail, employment centers, and a variety of housing types.
- *Density* (20-40%)—best practices include compact development, increasing the number of persons, jobs, or housing units per unit of area.
- *Distance to transit* (20-50%)—best practices include transit-oriented development, meaning development within a short walking distance of a transit stop, typically a quarter mile or half mile at most.
- *Destination accessibility* (30-60%)—best practices include "infill" development, compact development that takes place in already developed areas located near a large number of existing everyday destinations including jobs.

Concerted policy efforts around land use have the opportunity to save considerable energy by encouraging a shift from business-as-usual development patterns. *Growing Cooler*, the most comprehensive review of research on the connection between land use and vehicle travel, estimates the potential for 10-14% reduction in total U.S. VMT by 2050, resulting in 7-10% reduction in total U.S. transportation carbon dioxide (CO_2) emissions in 2050 relative to business as usual (Ewing et al. 2008). Other analyses have identified even greater opportunities. Vision California, a study completed to assist in the implementation of the state's goals of greenhouse gas emission reductions from land use and infrastructure development, estimated a possible statewide reduction in VMT and transportation CO_2 emissions of 38% by 2050 relative to business as usual (Calthorpe Associates 2011).

Evidence from Consumption Patterns

Existing energy consumption patterns also point to the impact of location-efficient development on energy consumption. Although only a rough indicator of location efficiency and not indicative of the full variety of location-efficient strategies, population density (Census 2010) is strongly correlated with economy-wide energy intensity (EIA 2011b) among U.S. states (see Figure 1). As population per square mile increases, energy use per dollar of economic activity within the state decreases. These variables have a correlation over 0.51, meaning population density can predictably explain more than half of actual energy intensity in a state, a high level of correlation among predictive variables of energy intensity.

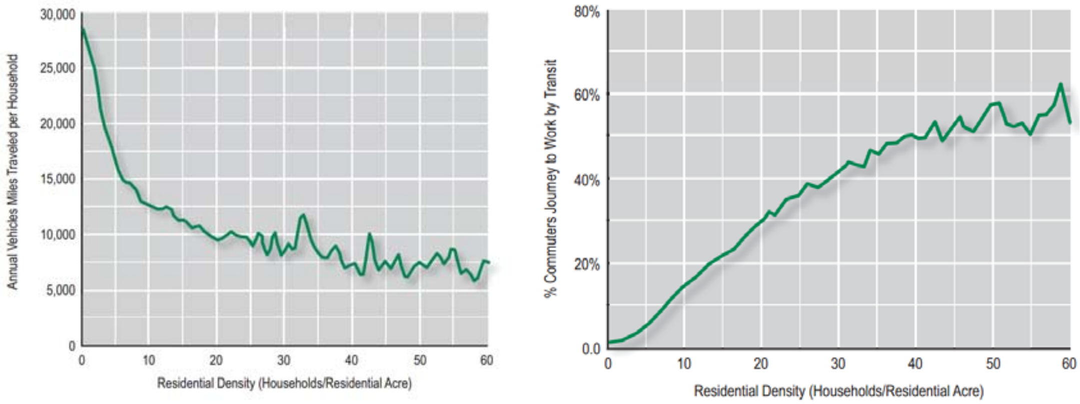
Figure 1. Population Density and Energy Intensity in U.S. States—As Population Density Increases, Energy Intensity Decreases



Similar patterns are seen in sector-specific energy uses, most notably in transportation. For example, household transportation behavior and resulting energy use is closely related to residential population density. As neighborhood density increases, vehicle miles traveled decrease and transit ridership increases, as shown in Figure 2 (CNT 2010). This represents a shift from a less energy-efficient transportation mode to a more efficient one as a result of location.

Figure 2. Vehicle Miles Traveled and Journey to Work by Transit by Residential Density—As Housing Density Increases, Vehicle Miles Traveled Decrease (2a) and Transit Ridership Increases (2b)

Figure 2a. **Figure 2b.**

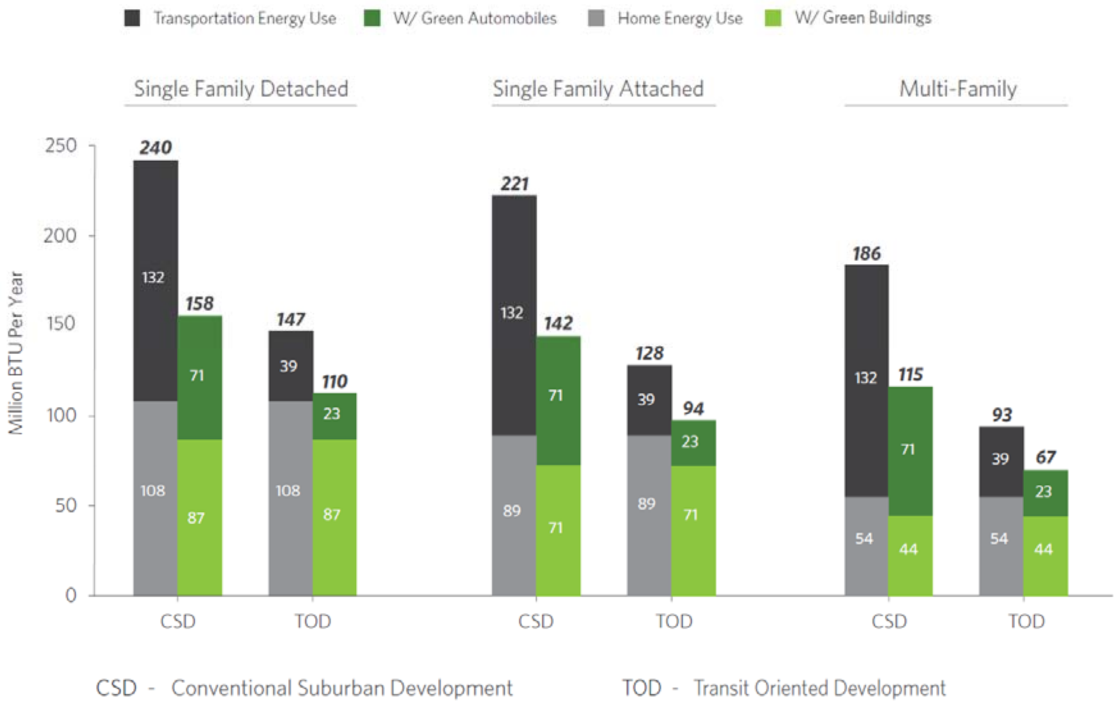


Source: CNT (2010)

Building Off of *Boiling It Down to BTUs*

A 2011 report released by the U.S. Environmental Protection Agency entitled *Location Efficiency and Housing Type–Boiling it Down to BTUs* (Hernandez, Lister, and Suarez 2011) used national average data to compare average household energy use—both building and transportation related—for three housing types (single-family detached, single-family attached, and multi-family) and two neighborhood development patterns (conventional suburban and transit oriented). As shown by the CSD and TOD bars for each housing type in Figure 3, the report found that greater total BTU savings could be achieved through a shift in the building's neighborhood surroundings from conventional suburban development to transit-oriented development than could be achieved through high-efficiency technology improvements for both the home and personal vehicles. These energy-saving benefits emerge primarily from decreases in vehicle ownership and related decreases in vehicle miles traveled per household.

Figure 3. Variations in Energy Consumption by Household Types



Source: Hernandez, Lister, and Suarez (2011)

The report provides a simple and elegant presentation of the topic with its emphasis on the household level and visual comparison of energy use between household types. However, while the report offers an important and provocative critique to the technology-centric approach to energy efficiency that has dominated for over thirty years, its methodology does not allow for a nuanced discussion of the strengths and weaknesses of these two complementary energy saving approaches under real world conditions nor of how they vary based on variations in local characteristics. Secondly, the analysis does not consider how much improvement in location efficiency could be realistically implemented and how those savings compare to technology-based savings. As a related issue, the analysis does not explicitly consider time scale and as a result implicitly compares an "end state" of sorts for location efficiency to a relatively short time horizon for technology efficiency.

In the remainder of this paper, I will analyze changes in U.S. average household building and transportation energy use patterns based on forecasted changes in demographics, development patterns, and technology over the next two decades. This analysis will include a comparison of the contribution of each of the four efficiency strategies discussed in *Boiling It Down to BTUs*. Additionally, I analyze the variation in energy savings potential among U.S. states from transit-oriented development alone. The results will provide a deeper understanding of the balance of opportunities between location and technology efficiency around the country, and identify states with the greatest energy savings potential from TOD.

Comparing the Potential for Location Efficiency and Technology Efficiency

In developing an analysis to address these questions, I first recreated the simple and elegant model used in the *Boiling It Down to BTUs* report. Next, I updated the model with the latest values from the original data sources used: Residential Energy Consumption Survey (RECS) (EIA 2009) and the National Household Travel Survey (NHTS) (FHWA 2011). The RECS values remained those from the 2005 survey since data from its 2009 consumption survey had not yet been released, but I updated the values from NHTS from the 2001 release to the 2009 release. The values retrieved from RECS were average annual energy consumption by building type (single-family detached, single-family attached, and multifamily buildings of five or more units). The values from NHTS were the average number of vehicles per household and the average number of annual vehicle miles travelled per vehicle.

Housing and Vehicle Stock Shift Analysis

While *Boiling It Down to BTUs* determined the energy consumption of an average *individual* U.S. household in each of twelve combinations of four energy use characteristics, it did not attempt to analyze the current or potential *mix* of these twelve household types among all households in the country. In this section I look at the energy saving impacts resulting from different levels of presence of these characteristics in the overall stock of vehicles or housing..

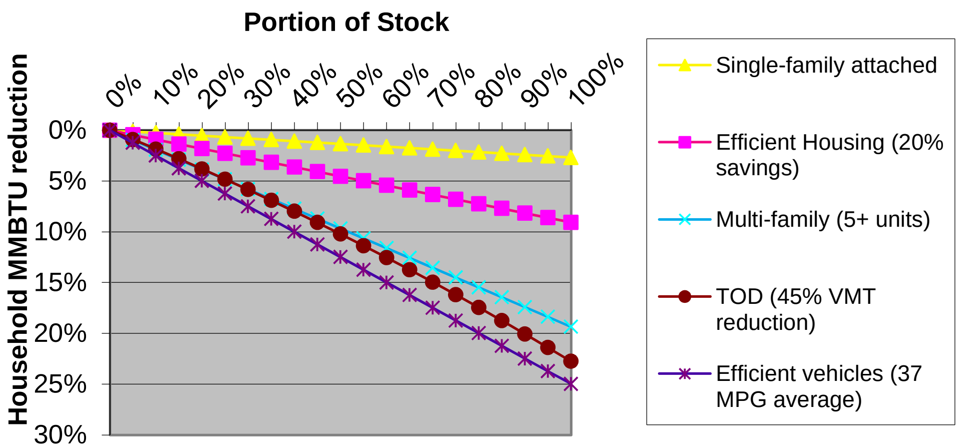
In the analysis I use the same four household characteristics and simplified associated options that are analyzed in *Boiling It Down to BTUs*:

- Vehicle efficiency (20 MPG or 37 MPG)
- Building efficiency (national average or 20% savings)
- Housing types (national average, single-family attached, or multi-family with five units or more)
- Neighborhood type (national average or transit-oriented development)

The first two characteristics are technology efficiency variables while the second two can be broadly referred to as location efficiency variables. However, the housing type is only concerned with the difference in average floor space for each type (e.g., smaller floor space reducing space condition energy requirements) and the location of housing units relative to other housing units (e.g., shared walls also reducing space conditioning energy requirements), whereas neighborhood type is concerned with the location of housing units relative to other features of a neighborhood (for our purposes this includes access to transportation options only). In general use, location efficiency primarily refers to the latter variable, location relative to other features in the neighborhood or region.

Next, I calculate change in the national average total household energy consumption gained through each increment of increased presence in overall stock (defined as the portion of all households to which the characteristic applies) with the more energy-efficient options for each characteristic (see Figure 4). The energy savings options, in increasing order of savings (y-axis) from each increment of increased presence in overall stock (x-axis), are single-family attached housing, high-efficiency housing, multi-family housing of five units or more, transit-oriented development, and high-efficiency vehicles. For each 1% increase in overall stock, these options averaged energy savings of 0.03%, 0.09%, 0.19%, 0.23%, and 0.25%, respectively.

Figure 4. Savings to Average Household Energy Use by Presence of the Energy-Efficient Option in Overall Stock



Accounting for Forecasted National Trends

The model above is simplified to allow for the theoretical energy saving contribution of each option to be isolated from other factors. However, it does not account for forecasted changes in energy consumption due to unrelated factors (e.g., fluctuations in fuel prices) or identify levels of adoption that are likely or feasible for each option (e.g., turnover rates, life-cycles, and resulting pace of market share changes, and resulting overall stock changes, are very different for vehicles compared to homes). To identify the energy savings opportunities while accounting for these real-world conditions, I use forecasts of average household building and transportation consumption to 2030 from the *2011 Annual Energy Outlook* (AEO) (EIA 2011a). In the paragraphs below I identify the assumptions used to estimate the potential levels of adoption through 2030 for each of the efficiency options.

Vehicle efficiency. Fuel economy standards and the pace at which new vehicles replace old are the main determinants of the efficiency of the average U.S. passenger vehicle. The most recent light-duty fuel economy regulations call for a corporate average fuel economy (CAFE) standard for new cars and light trucks of 35.5 MPG by 2016 (EPA 2010) and standards of 54.5 MPG by 2025 have been proposed (EPA 2011). However, in practice, vehicles meeting the 2025 proposed standard are likely to achieve closer to an average of 40 MPG under real-world conditions. Additionally, historically there has been a considerable delay between fuel economy standards for new vehicles and improvements in fuel economy for the overall national vehicle stock. The AEO 2011 "CAFE 6% Growth" scenario (based on a 2025 standard of 59 MPG and steady thereafter) estimates that the light-duty vehicle stock nationwide will average 35.3 MPG in 2030, up from 20.4 MPG in 2010. A scenario peaking at a 46 MPG standard in 2025 results in 31.8 MPG in 2030. For comparison, the AEO Reference Case assumes that the standards through 2016 will be adopted and a 35 MPG standard will be achieved by 2020 and held steady thereafter, resulting in a 27.0 MPG stock average in 2030 (EIA 2011a). For our purposes, the AEO reference case scenario (reflecting current policy) will serve as the reference forecast scenario with the AEO CAFE 6% scenario serving as the high case (reflecting slightly better fuel economy for the national vehicle stock than would be expected under the proposed 2025 standards).

Building efficiency. The technical efficiency of homes depends on the level of building construction activity—including the amount of new construction and the number of energy efficiency retrofits in existing homes—and the efficiency improvements achieved in the new and retrofit construction. The AEO 2011 Reference Case projects average energy consumption per home of 81.7 MBtu in 2030, down from 99.7 MBtu per home in 2010, a savings of 18%. This scenario assumes total U.S. households of 141.18 million, up from 114.74 million in 2010, a 23% increase. Average home size increases considerably from 1,686 to 1,938 square feet, while housing types do not shift significantly (the portion of households in multifamily units increases only slightly from 22.3% to 23.2%). Based on these numbers, it is safe to state that the projected energy savings is not coming from a significant shift to more efficient housing types or from smaller homes. Although other factors such as energy costs may also play a factor in these projected energy savings, most of these savings are likely to be coming from technological efficiency in new buildings and improvements to existing buildings. AEO 2011 also contains a "high technology" case that assumes quicker adoption of efficiency standards and technology in new housing construction and a "low technology" scenario that assumes no improvements from 2009 technologies in residential appliances and building shells. These scenarios result in household average consumption of 74.3 MBtu (25.5% savings from 2010) and 87.3 MBtu (12.4% savings) respectively in 2030 (EIA 2011a). For our purposes, the AEO Reference scenario can serve as a reference forecast case and the high and low technology scenarios will serve as alternatives.

Housing types. The mix of housing types depends primarily on the rate of new housing construction and the portion of the new construction that is devoted to higher efficiency housing types. The current housing type mix by number of housing units in the U.S. (according to the 2005 RECS) is 64.9% single-family detached, 6.8% single-family attached, 7.0% multifamily (2-4 units per building), 15.0% multifamily (5 or more units per building), and 6.2% mobile homes (EIA 2009). As previously mentioned, AEO projects a small increase in the portion of homes in multifamily buildings, accounting for an additional 1% of the total housing market by 2030. Other studies have projected greater increases for non-detached housing to meet the demands brought on by shifting preferences and demographics (Pitkin and Myers 2008). For our purposes, the AEO reference case will be integrated into our reference forecast scenario. In it we will assume all the new multifamily is of 5 units or greater and assume an additional 0.5% of the stock of single-family attached by 2030. For a high adoption case, we will assume aggressive market share growth in all efficient housing types (an additional 5% of the total housing stock for multifamily of 5 or more units, 2.5% for 2 to 4 unit multifamily, and 2.5% for single-family attached).[1] The shifts in both cases come at the expense of the single-family detached and mobile home market shares. The high case results in a relatively flat total number of single-family attached households, with growth over 20 years of only 4.5 million households compared to growth of 16.5 million in the reference scenario.

[1] Although larger shifts in the market are technically possible, housing is a durable asset resulting in slow market shifts. Likewise, legal and social barriers to a wholesale shift to attached housing exist in many parts of the country.

Neighborhood types. The mix of neighborhood types between conventional suburban development and transit-oriented development is influenced by many factors including housing development policy, consumer housing market preferences, transit investment, and, ultimately, the amount of housing construction located adjacent to transit. Reconnecting America (2004) and the Center for Transit-Oriented Development (CTOD) have developed market demand forecasts for TOD based on current and projected housing and transit development in the 42 metropolitan regions with the most significant transit systems. Using a growth function between the actual number of TOD households in 2000 and the CTOD forecast to 2030 (CTOD 2008) and accounting for growth in total households, approximately 7.3% of all U.S. households were TOD households in 2010 and 10.8% will be in 2030. This TOD growth rate is included in our reference forecast case.

In an alternative low case, TOD households are frozen at 7.3% of households in all years. In the high case, TOD households are assumed to grow such that they are 21.5% of all households by 2030, double the CTOD projections for that year. As a practical matter, because the pace of the high case would put TOD adoption above the level of new household creation in the later years, it could not be achieved through a housing development strategy alone and would also require conversion of existing housing to TOD through the development of new or expanded transit infrastructure.[2] Using research on travel behavior related to transit-oriented development (CNT 2010), I assume that households in TOD neighborhoods on average have a 45% reduction in vehicle miles traveled.[3] I apply this savings to the average household VMT from the 2009 NHTS projected out to 2030 using the annual growth rates from AEO 2011. To determine transit-related energy consumption over the 20 year period, I apply the static assumptions that were used in *Boiling It Down to BTUs*.

Results. The forecast analysis shows the impacts that variations in the four energy consumption characteristics (housing technology, vehicle technology, housing types, and neighborhood types) have on projected future household building and transportation energy consumption. For building energy use, our reference case estimates a reduction in average household energy use of 18.2% from the 2010 average of 99.8 MBtu. The high scenarios each result in further savings from the reference forecast: a 2.7% additional reduction from the high housing type scenario; 7.4% additional from the high technology scenario; and 9.9% additional when the two high scenarios are combined (see Figure 5).

For transportation energy use, our reference case (current CAFE standards and the CTOD projected TOD demand) projects a 15.2% reduction in average household consumption by 2030 from the 2010 baseline of 109.6 MBtu. The high TOD scenario results in an additional 3.9% reduction by 2030. The high CAFE standard scenario results in an additional 18.9% savings by

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[2] The mix of TOD deployment strategies (new housing near transit versus new transit near housing) as a practical matter would also influence the future stock of housing types. Because of higher land values near transit, new housing near transit is more likely to be multifamily or single-family attached.

[3] The average savings from transit-oriented development homes as identified in *Boiling It Down to BTUS* is arguably too high. The calculations used assume a VMT reduction for TOD households of nearly 75% while most literature on the topic (including CNT 2010) finds an average VMT reduction of closer to 45% in all but the densest TOD.

the final year. When combined, the two high scenarios result in an additional 22.7% savings in 2030 in comparison to the reference case (see Figure 6).[4]

When looking at overall household energy use across the various scenarios, greater energy savings result from a technology emphasis in comparison to a location emphasis and greater savings result from a transportation emphasis in comparison to building emphasis (see Figure 7). Of the four efficiency options I analyzed, the high case vehicle fuel economy standard had the single largest impact. The efficient building type scenario had the lowest impact when implemented in isolation. The reference case results in a 16.7% decrease in average household energy consumption from 2010 to 2030, while the "Kitchen Sink" scenario, consisting of the high cases for all four energy efficiency characteristics, results in a 33.3% decrease over the twenty years.

Figure 5. Building Energy Use Forecasts

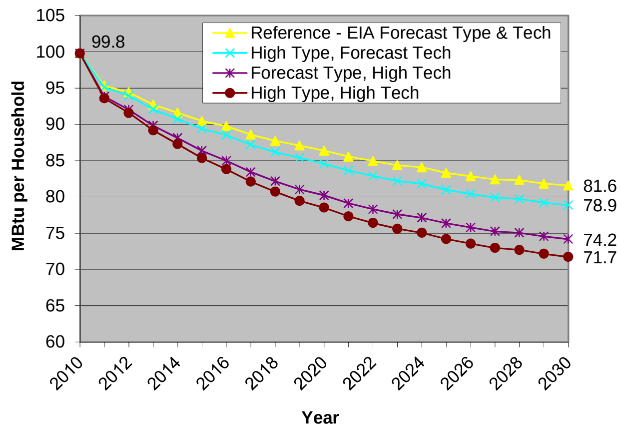
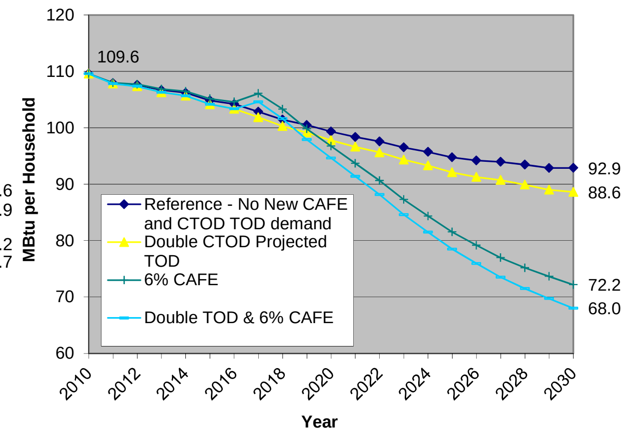
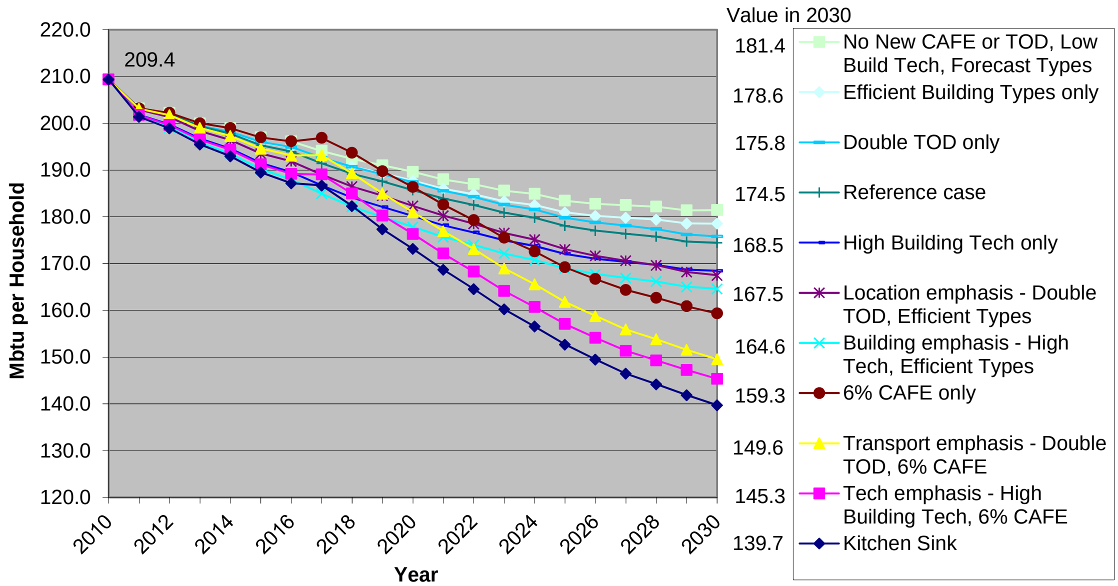


Figure 6. Transport Energy Use Forecasts



[4] The brief jump of consumption in 2017 and 2018 above the reference forecast in the high scenarios is the result of a small decrease in fuel efficiency across the vehicle stock in those years as projected in the Annual Energy Outlook 6% CAFE growth scenario.

Figure 7. Household Energy Use Forecasts[5]



Discussion

From this analysis of forecasted nationwide trends and potential energy savings from the options by 2030, several items arise. First, it becomes clear that the definition used in *Boiling It Down to BTUs* of an "efficient" home as 20% savings from the average for the housing type is not sufficient for a nationwide projection out to 2030. The AEO reference forecast projects nearly 20% savings for the *average* home from 2010 to 2030, making the 2030 average home an "efficient" home by 2010 standards. This is the equivalent of 100% of housing stock, implying that savings from building technology have the opportunity to be greater than identified in the report. This issue also exists to a lesser degree for vehicle technology. While the high scenario projection of a fleet *average* MPG of 35.3 does not quite reach the *Boiling It Down to BTUs* definition of efficient as 37 MPG, it is close. The difference emerges because the *BTUs* report is using definitions of "efficient" relative to current efficiency levels, while this analysis looks at expected changes in efficiency twenty years into the future.

Second, location efficiency strategies, both building type and neighborhood type, appear less effective in this analysis of forecasted trends when compared to the theoretical savings from the stock shift analysis, which did not consider existing real-world stocks or time horizons for implementing the more location-efficient options. Because of their integration with the built environment, location efficiency strategies can take longer to implement. The combination of the existing low presence of location-efficient options in current housing stock, the inefficient development patterns (including large lot, single-family detached homes with limited household access to transit) of the past few decades that are likely to be "locked in" for at least several more decades, and the relatively slow projected pace of new housing development all put location efficiency at a disadvantage in comparison to technology efficiency strategies. Technology efficiency can often be deployed more quickly. In the case of building technologies, many can be

[5] "Only" scenarios represent changes relative to the "No New" scenario. "Emphasis" scenarios represent changes relative to the "Reference Case" scenario.

integrated into both new and existing construction, and at the discretion of contractors or homeowners independently of other decision-makers in the building or surrounding neighborhood. Adoption of high-efficiency vehicle technology benefits from the relatively short lifecycle of vehicles when compared to that of homes. These important deployment issues are not analyzed in *Boiling It Down to BTUs*, resulting in an analysis that is not appropriate for the purpose of prioritizing energy savings investments.

On the other hand, the low presence of location-efficient options in the current stock and the projected demand increases do provide significant opportunities to achieve energy savings, particularly from TOD. And potential energy savings are large, even if they appear small in comparison to the technology efficiency options. The additional savings of 7 MBtus per household beyond the reference case achieved from the advanced location efficiency strategies in 2030 (and not counting those already incorporated in the reference case) is equivalent to 988 trillion BTUs annually nationwide, or 0.9% of *all* projected U.S. energy consumption in that year. Additionally, the location efficiency interventions analyzed here are among the most important, but not the only ones. If additional location efficiency strategies are pursued simultaneously, then greater saving will result due to system interactions. Finally, the cost of many location efficiency strategies can be quite low. For example, revised land use ordinances to allow more multifamily construction and more housing units around existing transit can happen in the course of regular local zoning revisions. Creation of TOD is not limited to new housing development—it can also be created through the development of more high quality transit and new stops to serve existing housing. Some strategies, like expanded transit service, are of higher cost, but the energy savings that result may be only one of many benefits (e.g., affordable transportation, increased mobility, decreased traffic congestion, neighborhood economic development). In many cases, these co-benefits will be of greater value to policymakers and stakeholders than the energy savings.

State Variations in Transit-Oriented Development Efficiency Potential

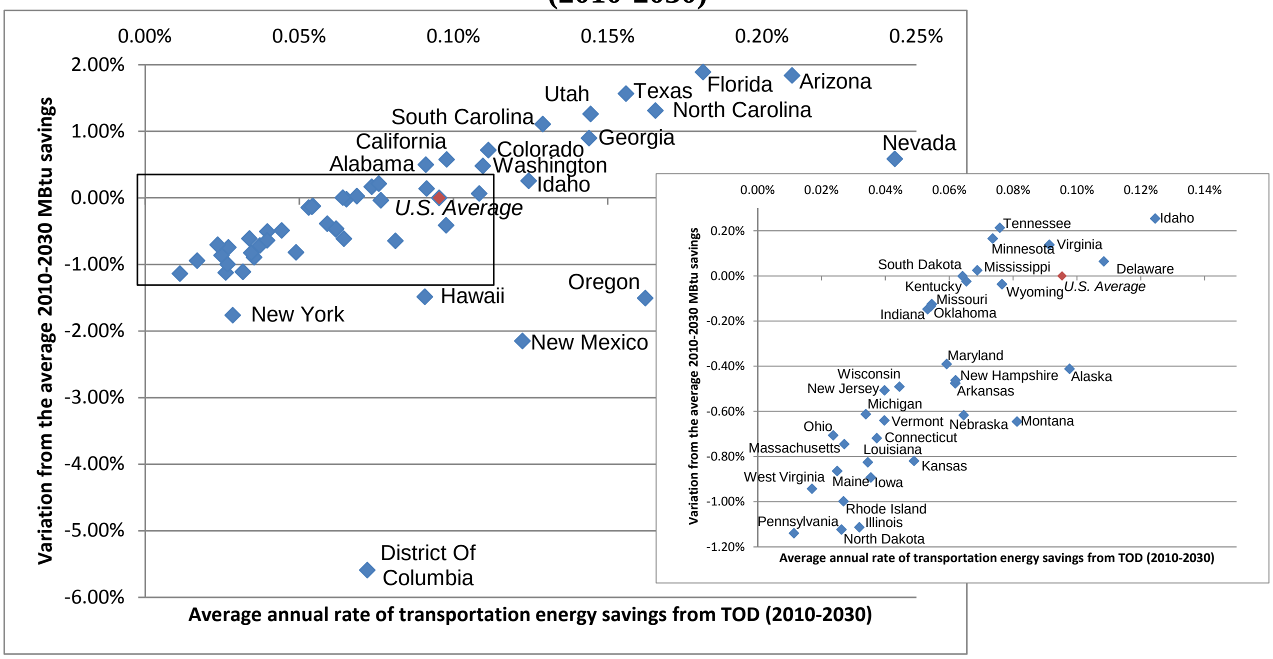
Transit-oriented development has the potential to save considerable energy, and is one of the most potent location efficiency strategies. But the savings opportunities from TOD are not the same everywhere across the county. In this section I compare the savings potential from TOD for each U.S. state. While much policy relating to TOD occurs at the local and metropolitan government levels, states also play an important role in that they manage a large amount of transportation funding, can adopt policies to encourage TOD over a large area, and often develop statewide energy efficiency and greenhouse gas reduction targets to which TOD can contribute.

To determine estimates of the TOD presence in current housing stock in each state I used NHTS 2009 state-level VMT data disaggregated by housing density ranges. Any households within a density range with a household average VMT of less than 11,000 annually (a reduction of approximately 45% from the national average VMT) were counted as TOD households. While this method is very rough and likely undercounts or overcounts TOD in many states, it results in a national total TOD housing stock of 8.5% of households, not too far from the 7.3% projected by CTOD for 2010. And because of the focus on VMT patterns, this method captures data on other location-efficient configurations resulting in decreased VMT (other manifestations of the "Five D's"), in addition to TOD.

The resulting number of TOD households for each state in 2009 were then increased each year thereafter by the product of the national average percentage of new households that would be TOD households in that year based on the CTOD projection and the increase in households in the state that year as projected by Moody's Analytics (2012). The assumption behind this calculation is that neighborhood types for existing households are largely "locked-in" and that new households provide a larger opportunity for new TOD.[6] Transportation energy consumption was then calculated for each state using the same methodology as used for the national analysis.

Figure 8 shows both the average annual savings to state household transportation energy consumption resulting from new TOD for 2010 to 2030 as well as each state's variation from the national average transportation energy savings from TOD and fuel efficiency improvements combined for the entire time period. States with the highest values on both axes present the greatest opportunity for transportation energy savings from TOD from the perspective of both *total* BTU savings and *relative* energy savings from the state's current baseline.

Figure 8. State Transportation Energy Savings Rates and Variations in Absolute Savings (2010-2030)



In most cases the states with below average total energy savings are characterized as such because they have an existing above-average TOD household share as calculated through the NHTS data, and as a result decreasing marginal savings from new TOD. While in general these values give a correct indication of existing TOD housing stock and average VMT (e.g., the District of Columbia, New York, and Hawaii, which all have low average household VMT and high TOD housing stock), in some cases the limitations of the NHTS data and the unique

[6] While it accounts for differences in current TOD stock, the analysis does not account for variations in expected future TOD adoption rates in each state. In this sense, it provides information on the *technical* potential for energy savings (using national average adoption) but not the *policy* potential, which would account for policy and incentive differences within each state. If TOD is adopted faster nationwide than the CTOD projections predict, than energy savings will increase. Likewise, states achieving higher (or lower) than average future TOD adoption would see larger (or smaller) energy savings than presented in this analysis.

transportation patterns of an individual state result in skewed values (e.g., New Mexico, which has a higher average VMT than its value represents).

The higher the potential annual energy savings rate from TOD in a state, the higher the expected household growth in the state that can likely be accommodated by TOD. This value is the more important value for states wanting to know how much TOD investments can contribute to their energy savings goals. Although all states have some saving opportunities from TOD, many of the states with the fastest growing populations have the greatest potential for energy savings: Nevada, Arizona, Florida, North Carolina, and Texas all have above a 0.15% annual transportation energy savings potential from TOD. This analysis does not account for planned transit system expansion in each state, another important factor in determining the future growth in the TOD housing stock. Such data on existing and proposed transit stations and adjacent populations in 54 metropolitan areas across the U.S. has been complied in the TOD Database (CNT 2012), but was not aggregated at the state level at the time of writing. Accounting for new transit stations would likely increase the energy savings potential for many states with growing public transportation systems.

Conclusion

While location efficiency strategies contribute less energy savings than technology efficiency under forecasted market conditions, TOD and other location efficiency strategies still can achieve significant energy savings and are important components of a comprehensive energy efficiency strategy. The timeframe for implementation of location efficiency tends to be longer than for technology efficiency, but the energy saving impacts can persist for many decades. Conversely, inefficient location choices also tend to have long-lasting impacts. Location efficiency is a particularly important energy efficiency strategy for states experiencing high population growth and those investing in new transit. The marginal cost of location-efficient choices in these communities is often very low. The energy savings benefit from location efficiency is often only one of many resulting benefits. These benefits are of importance to a large variety of stakeholders, creating a network of potential partners for energy efficiency advocates.

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