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TO Sandrine Thibault, Burlington Department of Zoning & Planning

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SUBJECT Task 2: Compact Development, Travel Patterns, and Greenhouse Gas Emissions – Literature and Metrics

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INTRODUCTION

The City of Burlington, VT is currently in the process of developing a land use and development master plan for its downtown/waterfront area. The City envisions an aggressive plan that actively promotes climate-conscious development and transportation strategies. As a part of that process, identified as Task 2 of the Climate, Energy and Green Infrastructure Analysis, the City's Department of Planning & Zoning has contracted Industrial Economics, Inc. (IEc) to provide information helpful for assessing potential greenhouse gas emissions reductions that could be realized by promoting additional development in downtown Burlington, rather than at the suburban fringe.

This memorandum presents IEc's work under this Task. It discusses the key literature on the relationship between the built environment, vehicle miles traveled (VMT), energy use, and CO_2 emissions, and provides an information resource for communicating the benefits of shifting development away from outlying areas and toward the downtown/waterfront area. The memo also identifies relevant local data sources and metrics that can be used to track key environmental outcomes over time.

Our key findings are as follows:

- The literature suggests that denser development, on its own, will not have a significant impact on citywide VMT or CO_2 emissions, particularly for the relatively modest changes in density expected in Burlington over the next several years. Rather, other built environment factors appear to play a larger role in shaping travel behavior. If increased density is coupled with other aspects of compact development, such as a well-balanced mix of land uses, short distances from homes to key destinations, a pedestrian-friendly street network, and accessible transit, greater CO_2 savings could result.
- The literature indicates that on the *household level*, individuals or families choosing to live in a compact development rather than in a sprawling area are likely to have much lower VMT. Thus, increasing the housing available in the downtown/waterfront area would provide greater opportunities for residents to lessen household-level environmental impact and reduce transportation costs. Moreover, because the citywide VMT impacts of compact development may be modest, planners and others in Burlington may wish to focus on household-level savings when promoting the downtown/waterfront development plan.
- There does not appear to be sufficient data available for Burlington officials to directly measure environmental benefits *caused by* changes in the City's built environment. However, local-level

data are available that will enable officials to monitor whether changes in VMT, energy use, and CO_2 emissions are occurring *in tandem with* changes to the City's development patterns. These data will enable the City to ascertain whether its net environmental impact is growing or shrinking.

The memo is organized as follows. We begin by summarizing the literature on the relationship between the built environment and travel behavior, as measured by VMT. We discuss the relative importance of different built environment variables in influencing VMT; the link between public transportation, VMT, and CO_2; the methodological issue of selection bias; and the overall potential for compact development to reduce VMT on the city or household level. The next section details the relationship between VMT and CO_2. We then briefly explore the dynamics of compact development and residential energy use. We conclude by identifying local data sources and specific metrics that can be used to measure Burlington's environmental impacts as it relates to transportation and the built environment.

LITERATURE ON THE BUILT ENVIRONMENT AND VEHICLE MILES TRAVELED (VMT)

In this section, we explore how the built environment influences levels of driving, expressed as VMT. This is central to understanding the likely environmental impacts of Burlington's downtown/waterfront development plan.

Total VMT Reductions from Compact Development

Growing Cooler, a major work by highly regarded authors in the area of urban development and travel, and the Special Report on the same topic by the Transportation Research Board (TRB) take fairly similar approaches to estimate the overall reductions in VMT and CO_2 that could be expected over the next few decades due to more compact development. Each group of researchers makes assumptions in a number of areas, including:

- Key factors that drive estimates of carbon emissions;
- The rate at which existing buildings will be replaced;
- The share of future development that can be expected to be compact rather than sprawling;
- The reduction in household VMT per capita associated with less sprawling development; and
- The relationship between VMT and CO_2 emissions.

Researchers' assumptions diverge significantly, so that whereas Growing Cooler estimates that compact development could result in a 7 – 10 percent decrease in U.S. transportation-related CO_2 below business as usual, TRB's 'moderate' scenario predicts just a 1.3 – 1.7 percent decrease.[1] On a similar note, while Bartholomew (2007) found in a review of regional growth simulations that compact development scenarios reduced VMT by an average of just 2.3 percent compared to trend scenarios, a subsequent meta-analysis by Bartholomew and Ewing (2009) found an average reduction of 7.9 percent, with substantial variability between individual simulations.[2]

In a critique of the TRB report, Ewing, Nelson, and Bartholomew (co-authors and contributors to Growing Cooler) argue that TRB's approach is too conservative. The authors point to the fact that the TRB ignores commercial development entirely, assumes a building replacement rate for residences implying a 500-year building lifespan, and (in their view) fails to adequately address changes in housing

[1] Ewing, Reid et al. Growing Cooler: The Evidence on Urban Development and Climate Change. Urban Land Institute, 2008 P. 35. See also National Research Council Transportation Research Board. "Special Report 298: Driving and the Built Environment: The Effects of Compact Development on Motorized Travel, Energy Use, and CO_2 Emissions." National Academy of Sciences, 2009. http://onlinepubs.trb.org/Onlinepubs/sr/sr298.pdf. P. 155.

[2] Bartholomew, Keith. "Land Use-Transportation Scenario Planning: Promise & Reality. Transportation 34. 2007. See also Bartholomew, Keith and Reid Ewing. "Land Use-Transportation Scenarios and Future Vehicle Travel and Land Consumption." Journal of the American Planning Association 75(1). Winter 2009. Cited in Moore et al. 2010, p. 569.

preferences that could come as the baby boomer generation enters retirement age.[3] It is worth noting, however, that even if these authors are correct, their own forecast of a 7 – 10 percent reduction below baseline CO_2 emissions is relatively small in comparison to the targets envisioned in most climate change policy discussions. This suggests that while a land use change can play a part in meeting climate change goals, it will not be sufficient on its own.

Key Built Environment Variables

There are several factors that distinguish compact development from sprawl. While early work focused largely on residential density, it soon became clear that residential density is an insufficient measure; on the basis of density, Los Angeles would be among the most compact cities in the nation, while Portland, Oregon would be sprawling. More recent work has suggested that density may be less important than other variables in influencing travel patterns. The literature often refers to the key built environment variables as the "four Ds:"

- Density, typically measured as people, jobs, or dwellings per unit area;
- Diversity, referring to the number of different land uses in an area and the degree to which they are balanced or mixed;
- Design, comprising street design elements such as street interconnectivity, block length, presence of sidewalks, etc.; and
- Destination accessibility, measured by the number of jobs or other key destinations (e.g., retail shops) reachable within a given travel time.[4]

A fifth D, distance to transit, is sometimes included as well; Ewing et al. note that "if we could think of an appropriate label, parking supply and cost might be characterized as a sixth D."[5] Nonetheless, most research to date has focused on the first four variables. The influence of these and other factors on travel behavior is often expressed in terms of 'elasticity,' that is, the proportional rate by which a change in an independent variable leads to a change in a dependent variable. Elasticity of -0.2, for example, would mean that a 100 percent increase in an independent variable (such as residential density) would result in a 20 percent decrease in the dependent variable (such as VMT), or that a 10 percent increase in one would lead to a 2 percent decrease in the other. A larger elasticity, whether positive or negative, means that a dependent variable is more responsive, whereas lower values connote a weaker link between the two.

Density and VMT

Density is probably the most studied dimension of land use, perhaps because it is easy to measure and communicate. However, the effects of higher densities on travel behavior are not necessarily straightforward; for example, shorter distances may encourage greater trip frequencies. Nonetheless, researchers agree that denser areas are generally associated with lower VMT.[6] One of the most well-known studies in this area was conducted by Holtzclaw et al. (2002). The researchers compared different neighborhoods in the San Francisco, Los Angeles, and Chicago metropolitan areas and found that auto ownership and use dropped systematically as residential density increased. Observers have critiqued this particular study, but the general pattern has held up in other research.[7]

Still, there is considerable disagreement as to the size of the density effect. The Victoria Policy Institute estimates that doubling urban densities can result in a 25 – 30 percent reduction in VMT, or slightly less

[3] Ewing, Reid et al. "Response to Special Report 298 Driving and the Built Environment: The Effects of Compact Development on Motorized Travel, Energy Use, and CO2 Emissions." Metropolitan Research Center, University of Utah. September 16, 2009. http://www.smartgrowthamerica.org/documents/ResponsetoTRBSpecialReport.pdf

[4] Ewing, et al. 2008, p. 67.

[5] Ibid.

[6] National Research Council Transportation Research Board 2009, p. 51.

[7] Ibid, p. 55.

when controlling for other variables.[8] A Northeast-Midwest Institute working paper similarly states that "Most studies reviewed indicate that any doubling of density corresponds to lowering of VMTs by about 25 percent," i.e., an elasticity of -0.25.[9] In one of the largest such studies, Cervero and Murakami (2010) looked at 370 urban areas in the U.S. and found that VMT per capita had an elasticity of -0.381 with respect to density, with the direct effect of density being offset somewhat by the travel-inducing effects of denser roadway networks and greater access to destinations.[10]

Other researchers have found considerably smaller density impacts than those found in the above studies. Looking across the literature, the Transportation Research Board estimates that VMT has an elasticity of -0.05 to -0.12 with respect to density, or somewhat lower after separating out other land use factors.[11] In one of the early seminal works in the area, Ewing and Cervero (2001) look across multiple studies and derive an elasticity of -0.05 for both vehicle trips (VT) and VMT).[12] The same authors updated their meta-analysis in 2010 and found that in the literature, VMT had an average elasticity of -0.04 with respect to household and population density.[13] Walters and Ewing cite a similar range of -0.05 to -0.10.[14] These results imply that doubling residential density across an entire city would be expected to produce VMT per capita savings on the order of 5 – 10 percent. On a similar note, other studies have concluded that only at extreme levels does density have a substantial effect; a 2004 Department of Transportation study identified a threshold value of 6,000 – 7,000 people per square mile for density to have a meaningful impact on VMT per capita.[15] Other studies have not evaluated whether there may be a minimum threshold at which increased density has an impact. However, almost all research on the subject has taken place in urban areas more populous (and presumably denser) than Burlington. It is unclear what implications this may have for Burlington.

Other Built Environment Variables and VMT

Other land use factors appear to be more important than density in influencing VMT. Destination accessibility specifically appears to be quite influential. Destination accessibility can be measured in different ways, but in broad terms it refers to the number of jobs or other attractions reachable within a given travel time; this tends to be highest at central locations that have several key destinations in close proximity.[16] (Walk Score, available for public use at http://www.walkscore.com, provides an easy-to-understand destination accessibility measure.) Ewing et al. (2008) estimate that elasticities of VMT for diversity and design are approximately as strong as for density, but destination accessibility is much stronger at -0.20.[17] Walters and Ewing (2009) similarly estimate the elasticity of destination accessibility at -0.20 to -0.30.[18] In their updated meta-analysis, Ewing and Cervero (2010) find that the other 'D'

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[8] Walters, Jerry and Reid Ewing. "Measuring the Benefits of Compact Development on Vehicle Miles and Climate Change." Environmental Practice 11(3), September 2009. P. 203.

[9] Evans Paull. "Energy Benefits of Urban Infill, Brownfields, and Sustainable Urban Redevelopment: A Working Paper." Northeast-Midwest Institute, December 2008. http://www.nemw.org/images/stories/documents/energy_benefits_infill_brfds_final_12-08.pdf. P. 5.

[10] Cervero, Robert and Jin Murakami. "Effects of Built Environments on Vehicle Miles Traveled: Evidence from 370 US Urbanized Areas." Environment and Planning 42, 2010. P. 412-413, 415-416.

[11] National Research Council Transportation Research Board 2009, p. 4.

[12] Ewing, Reid and Robert Cervero. "Travel and the Built Environment." Transportation Research Record 1780, 2001. Cited in Ewing et al 2008, p. 70.

[13] Ewing, Reid and Robert Cervero. "Travel and the Built Environment: A Meta-Analysis." Journal of the American Planning Association 76(3), Summer 2010. P. 275.

[14] Walters and Ewing 2009, p. 205.

[15] Department of Transportation. "Emissions Benefits of Land Use Strategies." 2004. http://www.fhwa.dot.gov/environment/conformity/benefits. Cited in Moore, Adrian et al. "The Role of VMT Reduction in Meeting Climate Change Policy Goals." Transportation Research Part A 44, 2010. P. 570.

[16] Ewing et al. 2008, p. 68.

[17] Ewing, Reid and Robert Cervero. "Travel and the Built Environment." Transportation Research Record 1780, 2001. Cited in Ewing et al 2008, pp. 70-71.

[18] Walters and Ewing 2009, p. 205.

variables have stronger effects than density, with measures of destination accessibility being the most important. The table below presents their key results with respect to VMT; they found the same general pattern with respect to walking and transit use.[19,20]

EXHIBIT 1: ELASTICITIES OF VMT WITH RESPECT TO BUILT-ENVIRONMENT VARIABLES

		TOTAL NUMBER OF STUDIES	NUMBER OF STUDIES WITH CONTROLS FOR SELF-SELECTION	WEIGHTED AVERAGE ELASTICITY OF VMT
Density	Household/population density	9	1	-0.04
	Job Density	6	1	0.00
Diversity	Land use mix (entropy index)	10	0	-0.09
	Jobs-housing balance	4	0	-0.02
Design	Intersection/street density	6	0	-0.12
	% 4-way intersections	3	1	-0.12
Destination accessibility	Job accessibility by auto	5	0	-0.20
	Job accessibility by transit	3	0	-0.05
	Distance to downtown	3	1	-0.22
Distance to transit	Distance to nearest transit stop	6	1	-0.05

Source: Ewing and Cervero 2010, p. 275.

It is important to note that when considering the impacts of the 'four Ds' on VMT, the reported elasticities may be additive.[21] Thus, policy interventions that produce changes in more than one of these variables could result in stronger impacts than those policies that affect only one of the 'four Ds'. For the same reason, changes in multidimensional sprawl indexes (such as Smart Growth America's sprawl index) tend to show greater impacts than research that focuses on measuring the VMT impacts of single variables. It is for this reason that Growing Cooler, one of the most significant works in this area, can report on studies showing roughly 30 percent differences in VMT per capita between the most sprawling and least sprawling U.S. cities (as measured by multidimensional sprawl indexes), or state that doubling the first four 'D' variables can be expected to reduce VMT per capita by about one-third.[22] This may also explain why some studies found significantly greater elasticities of VMT with respect to density than others; not all authors controlled for the other built environment variables that contribute to VMT.

In short, while density is clearly associated with a reduction in VMT, other neighborhood characteristics are equally if not more important, and increased density in itself is not a cure-all. Municipalities seeking to decrease VMT and attendant CO_2 emissions should pay attention to the other 'D' variables, rather than focusing single-mindedly on density.

Public Transportation

One of the ways in which compact development is expected to reduce energy use and greenhouse gas emissions is by facilitating mode shifting, in which travelers walk, bike, or ride public transportation, and thereby reduce automobile trips. Yet changes in development patterns do not guarantee that residents will shift modes.

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[19] Ewing and Cervero 2010, p. 275.

[20] Note that all of the works referenced in this paragraph are meta-analyses that themselves review several different individual studies.

[21] National Research Council Transportation Research Board 2009, p. 4.

[22] Ewing et al. 2008, pp. 6, 62, and 70-71.

The literature does not show that increased density, in and of itself, is associated with significantly greater levels of transit use. The meta-analysis by Ewing and Cervero (2010) found an average elasticity of transit use of just 0.07 with respect to residential density, and 0.01 for job density. The authors note that: "It is sometimes said that 'mass transit needs 'mass;' however, this is not supported by the low elasticities of transit use with respect to population and job densities" reported.[23] Of course, below some threshold of minimum density, there are simply not enough people to justify the existence of a transit route. However, factors other than density appear to drive decisions to use transit.

One such factor is greater access, defined as distance to transit. The literature is mixed on the extent to which greater access to transit can itself induce higher levels of ridership. The Transportation Research Board indicates that "a 10 percent increase in rail and bus route miles lowers the probability of driving by only 0.03 percent when New York, which is an outlier in terms of the amount of transit service, is excluded."[24] However, Ewing and Cervero (2010) find a much stronger effect for distance to transit stops, with an elasticity of -0.29 for transit usage.[25] This means that doubling the distance from the average home to the nearest transit stop is associated with a 29 percent drop in transit ridership.

Furthermore, while walking or biking will result in direct CO_2 emissions reductions, public transit has its own emissions that dampen savings realized by reduced automobile use. Ridership per vehicle is the key determinant in energy and emissions savings provided by public transit options. Moore et al. (2010) provide a critique based on the Department of Energy's Transportation Energy Data Book, which we update here with more recent data.[26] The average car in the U.S. uses 5,465 Btu per vehicle-mile, while the average transit bus uses 39,906. Thus, a bus would need to carry an average of 11.7 passengers at all times in order to be as efficient as a group of cars (assuming an average of 1.6 passengers per car).[27,28] Of course, if routes and schedules are already established, any passenger that chooses to use public transit rather than drive will reduce overall CO_2 emissions. Yet from a planning perspective, officials should be aware that a transit system (or an individual route) with relatively few passengers could actually increase greenhouse gas emissions.

Finally, it appears that selection bias may play a major role in determining varying levels of transit usage in different neighborhoods. That is to say, people who are very interested in using public transit may choose to live close to a bus or train stop. This is discussed in greater detail below.

Selection Bias

One of the key issues in research on travel and the built environment is the extent to which different neighborhood characteristics actually induce different travel behaviors, rather than such behavioral differences simply reflecting the pre-existing preferences of the residents who live there. In this context, *selection bias* means that studies that show less driving by residents of central urban areas may simply indicate that people who prefer not to drive choose to live in central areas, exhibiting what is known as self-selecting behavior. To the extent that reported results are driven by uncontrolled selection bias, in which this self-selection of living in a central area is not accounted for, studies will overstate the degree to which changes in the built environment will actually lead to changes in travel behavior.[29] Thus,

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[23] Ewing and Cervero 2010, pp. 275-276.

[24] National Research Council Transportation Research Board 2009, p. 73.

[25] Ewing and Cervero 2010, p. 275.

[26] Moore et al. 2010, p. 571.

[27] I.e., 39,906 Btu per vehicle-mile / (5,465 Btu per vehicle-mile / 1.6 passengers) = 11.7 passengers.

[28] Department of Energy Center for Transportation Analysis. "Transportation Energy Data Book." Edition 29, June 30, 2010. Table 2-12. http://cta.ornl.gov/data/index.shtml

[29] Xinyu Cao. "Exploring Causal Effects of Neighborhood Type on Walking Behavior Using Stratification on the Propensity Score." Environment and Planning A (42), 2010. P. 488.

understanding the degree to which selection bias exists is important to accurately predict the impacts of proposed changes in the built environment.[30]

The literature differs on the importance of self-selection in the observed correlation between built environment characteristics and travel behavior.[31] The Transportation Research Board (2009) identifies five comprehensive reviews of this literature and finds that "The majority of the studies reviewed find a statistically significant effect of the built environment after controlling for socioeconomic characteristics and self-selection. However, the survey authors characterize these results as 'mixed.'"[32] A later review by Cao et al. (2010) examined 38 studies and found that while many found evidence of self-selection, after controlling for this effect, virtually all of them still found that the built environment has a significant influence on travel behavior.[33]

Compared to the large number of papers exploring the built environment and travel behavior, relatively few studies have attempted to quantify the relative influence of self-selection versus environmental factors. Note, for example, that few of the studies examined by Ewing and Cervero (2010) and included above in Exhibit 1 controlled for self-selection. Ewing and Cervero do identify several other studies that control for selection bias, however. These works found that anywhere from 48 – 98 percent of differences in VMT and walking was due to environmental influences, with the balance due to self-selection.[34] A paper by Cao (2010) is especially noteworthy for its methodological approach, which uses propensity score stratification, a statistical technique ideally suited for controlling selection bias, to examine walking behavior in eight neighborhoods in northern California. Cao found that neighborhood type accounted for 61 percent of observed differences for destination-based walking and 86 percent for recreational walking.[35] Mathematically, this implies that if self-selection is not controlled for, the impact of the built environment would be overstated by 64 percent for destination-based walking and 16 percent for recreational walking.[36]

Some researchers have noted that the phenomenon of self-selection could *in itself* produce some changes in travel behavior if more compact developments are built. This would be the case if there is currently an unmet demand for pedestrian-oriented neighborhoods, which forces people to live in neighborhoods where they drive more than they ideally want to.[37] By providing opportunities for such residents to live in areas that satisfy their preferences, compact development could reduce VMT even if the effect was driven by self-selection rather than environmental factors as such.[38]

Overall, it is clear that both self-selection and environmental influences contribute to observed differences in travel behavior among residences of various neighborhood types. Although environmental factors appear to dominate, the literature suggests that where selection bias is not controlled for, the predicted impacts of compact development on travel behavior may be somewhat overstated. However, even where self-selection is important, areas that have unmet demand for pedestrian-oriented neighborhoods could achieve VMT reductions by creating compact neighborhoods that allow residents to choose housing that better reflects their preferences. Thus, Burlington's Transportation Plan notes, correctly, that "Transit

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30 National Research Council Transportation Research Board 2009, p. 58.

31 Ibid, p. 60.

32 Ibid, p. 66. The studies identified by the Transportation Research Board include Badoe and Miller 2000; Crane 2000; Ewing and Cervero 2001; Handy 2005; and Cao et al. 2008. See Transportation Research Board 2009 for complete citations.

33 Cao 2010, p. 488.

34 Ewing and Cervero 2010, pp. 266-267. The studies identified by Ewing and Cervero include Salon 2006; Zhou and Kockelman 2008; Cao 2010 (discussed in this report); Cao, Xu and Fan 2009; and Bhat and Eluru 2009. See Ewing and Cervero for complete citations.

35 Cao 2010, p. 500.

36 I.e., 1/0.61 – 1 =0 .64; 1/0.86 – 1 = 0.16. See Cao 2010, p. 502.

37 Cao 2010, p. 487.

38 Walters and Ewing 2009, p. 203.

services should be provided where higher-density, mixed-use development is anticipated well in advance, rather than re-routed in response to new development proposals after that fact."[39]

Household-level VMT Reductions from Compact Development

While the literature is mixed on the extent to which more compact development would lead to aggregate citywide reductions in VMT, researchers appear more unified in their assessment of the impacts for individual households choosing to live in a compact, centrally located neighborhood. Households living in more compact developments tend to have lower VMT for multiple reasons: shorter driving distances to work and other key destinations; the presence of public transportation networks as a viable alternative to driving; and the option to walk or bike instead of drive, due to the shorter distances involved.

The Canada Mortgage and Housing Corporation developed a statistical model of greenhouse gas emissions quantifying the empirical relationships between neighborhood characteristics, housing design, and locational factors on VMT and CO_2. The agency then applied the model to generic neighborhood types in the Toronto area. They found that households moving from an outer suburb to a central area would reduce their VMT by an average of 42 – 60 percent, depending on the particular neighborhood types involved. Households moving from an inner suburb to a central area would reduce their VMT by 20 – 35 percent.[40] Evans Paull, a prominent researcher in the field of urban redevelopment, equates the effect of an individual moving from the suburbs to an urban compact development to driving a hybrid vehicle, saving about two tons of CO_2 per year.[41]

Looking more broadly, Ewing et al. (2008) survey the range of primary research and identify 10 studies considering the effects of regional location of individual developments on travel and emissions. Overall, these studies show that "infill locations generate substantially lower VMT per capita than do greenfield locations, from 13 to 72 percent lower."[42] On the basis of this and other literature, Ewing et al. conclude that when comparing individual developments, compact development options will reduce the need to drive between 20 and 40 percent, as compared with development at the outer suburban edge with isolated homes, workplaces, and other destinations. Thus, one could assume a 30 percent reduction in VMT when comparing individual compact developments to homes built at the suburban edge.[43] As detailed below, this would translate into a 28 – 30 percent reduction in automobile-related energy use and CO_2 emissions for affected households. We discuss this link in the following section.

VEHICLE MILES TRAVELED AND CARBON DIOXIDE

All else being equal, every mile driven in an automobile result in a proportional increase in fuel consumption and greenhouse gas emissions. Thus, in proportional terms, any reductions in VMT caused by compact development should produce an identical reduction in automobile CO_2 emissions. However, shorter average trip lengths and lower vehicle speeds and CO_2 emissions may not fall by quite the same amount as VMT as a result of compact development.

A number of researchers simply assume a direct one-to-one correspondence between VMT and automobile CO_2 emissions. The TRB's major work, "Driving and the Built Environment: The Effects of Compact Development on Motorized Travel, Energy Use, and CO_2 emissions," uses this approach. So too

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[39] City of Burlington Department of Public Works, Department of Planning and Zoning, and Community Economic Development Office. "Moving Forward Together: Transportation Plan for the City of Burlington." Adopted March 28, 2011, p. 15. http://www.ci.burlington.vt.us/docs/4593.pdf

[40] Walters and Ewing 2009, pp. 200-201.

[41] Paull 2008.

[42] Ewing et al. 2008, p. 88. The studies identified include EPA 1999, 2001, and 2006; Hagler Bailly, Inc. 1998; Hagler Bailly, Inc. and Criterion Planners/Engineers 1999; IBI Group, Canada Mortgage, and Natural Resources Canada 2000; Allen and Benfield 2003; U.S. Conference of Mayors 2001; and SACOG 2007. See Ewing et al. 2008 for complete citations.

[43] Ewing et al. 2008, p. 9.

does Andrews 2008, which develops a framework for estimating greenhouse gas emissions from different types of development.[44] Using this method, VMT is typically translated into gasoline use using an average factor for fleet-wide automobile fuel economy. The Bureau of Transportation Statistics tracks and reports this number on a quarterly basis; as of 2008, the most recent year for which data was available, the average passenger car in the U.S. got 22.6 miles per gallon (mpg) and the average light truck got 18.1.[45] Because passenger cars accounted for 59 percent of miles driven,[46] this equates to an overall fuel efficiency of about 20.8 mpg, or inversely, 0.048 gallons per mile. This must be converted into CO_2; EPA uses a value of 19.4 lb. CO_2 per gallon gasoline (22.2 for diesel).[47] Thus, every mile driven in an automobile emits an average of 0.0481 x 19.4 = 0.93 lb. CO_2.

Yet development patterns not only influence the total number of miles driven; they also impact the duration and speed of those trips. When destinations are closer and more accessible, as would be expected in a compact development, trip lengths will be shorter. Because vehicles use more fuel and emit more CO_2 on starting up than in the course of driving, this means that drivers whose travel consists of shorter trips will use slightly more fuel per mile on average than drivers of longer trips. The California Air Resources Board estimates typical 'cold start' emissions at 213 grams CO_2 (0.47 lb., equivalent to about a half-mile of driving).[48]

Greater population and employment density would also be expected to lead to greater congestion, as more vehicles pack onto the roads. This will in turn lead to lower vehicle speeds and, again, greater CO_2 emissions per mile. Ewing et al. (2008) estimate that in a typical urban area, a 50 percent increase in density would lead to a 7.5 percent decrease in peak-hour driving speed; this in turn would cause a two percent increase in CO_2 per mile.[49] Taking into account penalties from both lower peak speeds and cold starts, they arrive at a VMT-CO_2 ratio of 0.93. That is, they project that a one percent reduction in VMT due to compact development translates into a 0.93 percent reduction in CO_2 from automobiles.[50]

Burlington appears to have relatively little traffic compared to the larger urban areas that are the focus of most travel-built environment research. For instance, the average commute time for workers in the Burlington-South Burlington metropolitan area is 18.8 minutes. By contrast, the Manchester-Nashua metropolitan area, in New Hampshire, has a mean commute time of 25.6 minutes, and the mean commute time in Boston is 28.5 minutes.[51] For this reason, changes in Burlington's development patterns – especially on the relatively modest scale likely to occur – may not add enough cars to result in an appreciable decrease in vehicle speeds. If this is the case, then the observed VMT-CO_2 ratio would be closer to 1.0. Thus, for Burlington, we recommend considering a VMT-CO_2 ratio of 0.93 as the lower bound, with an upper bound of 1.0.

RESIDENTIAL ENERGY USE

The literature on development patterns and energy focuses primarily on transportation choices. However, development modes also impact residential building energy use. This is mainly because compact

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[44] Clinton J. Andrews. "Greenhouse Gas Emissions Along the Rural-Urban Gradient." Journal of Environmental Planning and Management 51(6). November 2008, pp. 847-870.

[45] Department of Transportation Bureau of Transportation Statistics. "National Transportation Statistics Table 4-23: Average Fuel Efficiency of U.S. Passenger Cars and Light Trucks." January 2011. http://www.bts.gov/publications/national_transportation_statistics/

[46] Department of Transportation Bureau of Transportation Statistics. "National Transportation Statistics Table 1-35: U.S. Vehicle-Miles." July 2010. http://www.bts.gov/publications/national_transportation_statistics/

[47] Environmental Protection Agency. "Emission Facts: Average Carbon Dioxide Emissions Resulting from Gasoline and Diesel Fuel." EPA420-F-05-001. February 2005. http://www.epa.gov/otaq/climate/420f05001.htm#carbon

[48] Data based on EMFAC 2007, v2.3, provided by Jeff Long, California Air Resources Board. Cited in Ewing et al. 2008, p. 45.

[49] Ewing et al. 2008, p. 47.

[50] Ibid, p. 34.

[51] Data from U.S. Census Bureau, 2005-2009 American Community Survey. Table SO801: Commuting Characteristics by Sex. http://factfinder.census.gov/servlet/DatasetMainPageServlet?_lang=en&_ts=329045287912&_ds_name=ACS_2009_5YR_G00_&_program=

development tends to promote multi-family buildings and smaller single-family homes rather than larger, detached single-family dwellings. Such buildings have lower volumes and outside surface area per person, resulting in lower heating and cooling loads.

Looking at average levels of consumption, some studies have found that residents in multi-family units consume nearly 50 percent less electricity and total energy than single-family homes. However, because these studies do not account for income or other demographic characteristics, these results are not necessarily transferable to all situations. Keeping income and dwelling size constant and evaluating only the physical impacts of reduced surface area, researchers have estimated multifamily dwellings to use 20 percent less energy per person than single-family detached homes.[52,53] Kockelman et al. (2009), meanwhile, estimated that a family moving from a 2,400 sq. ft. detached single-family home (the U.S. average in 2007) to a modestly smaller 2,000 sq. ft. apartment would save an average of 37 percent of total energy use. Downsizing to a 2,000 sq. ft. detached single-family home would produce only modest savings of about 4.4 percent of total energy use.[54]

Interacting with this effect, compact development also affects residential energy use through location, via the heat island effect. Due to the thermal properties of most building materials, urban areas often experience warmer ambient temperatures than nearby rural areas. The annual average air temperature in a large city can be 1-3°C warmer than the surrounding area.[55] Shifting a greater proportion of development to urbanized areas will therefore expose residents to slightly warmer temperatures.

Ewing and Rong (2008) find that each 10 percent increase in a city's compactness (using a multi-attribute index) decreases heating degree-days by two percent and increases cooling degree-days by 4.7 percent.[56,57] In Burlington, which has a relatively cold climate, the heat island effect could actually result in a net decrease in energy use. The city has 7,710 heating degree days annually but just 462 cooling degree days,[58] so these percentage changes would translate into a decrease of 154 heating degree days and an increase of 22 cooling degree days. Energy savings from milder winters would therefore outweigh increased consumption during hotter summers. In practice, Burlington's heat island effect is likely small enough that the overall impact would be minimal.

Finally, observers have noted that more compact and centrally located development should lead to lower losses on electric transmission lines. Given the small distances involved, however, the effect is likely to be quite small, and it appears researchers have not attempted to quantify it.[59]

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[52] Naomi Freeman. "Connecting Energy and Smart Growth." Environmental and Energy Study Institute presentation, 2006. See also Viera, Robin and Danny Parker. "Energy Use in Attached and Detached Residential Developments: Survey Result." Florida Solar Energy Center, 2007. http://www.fsec.ucf.edu/en/publications/html/FSEC-cr-381-91/ Cited in Paull 2008, p. 7.

[53] Paull 2008, p. 12.

[54] Kockelman, K. et al. "GHG Emissions Control Options: Opportunities for Conservation." University of Texas, Austin, 2009. http://onlinpubs.trb.org/Onlinepubs/sr/sr298kockelman.pdf. Cited in Transportation Research Board 2009, pp. 175, 199.

[55] Environmental Protection Agency. "Heat Island Effect." June 17, 2011. http://www.epa.gov/heatisland/

[56] Ewing, Reid and Fang Rong, "The Impact of Urban Form on US Residential Energy Use." Housing Policy Debate 19 (1), 2008. Cited in Ewing et al. 2008, p. 111.

[57] Heating degree-days measure the number of degrees that a day's average temperature is below 65º Fahrenheit. For example, if the average temperature for a day is 50ºF, it would have 15 degree-days. Similarly, cooling degree-days measure the number of degrees that a day's average temperature is above 65ºF. Aggregating heating degree-days and cooling degree-days over an entire year provides a useful indicator for the total amount of energy needed to heat and cool buildings to maintain comfortable temperatures.

[58] National Oceanic and Atmospheric Administration National Weather Service. "Burlington, VT Monthly Totals/Averages HDD (base) 65," and "Burlington, VT Monthly Totals/Averages CDD (base) 65." http://www.erh.noaa.gov/btv/climo/BTV/monthly_totals/hdd.shtml and http://www.erh.noaa.gov/btv/climo/BTV/monthly_totals/cdd.shtml

[59] Andrews 2008, p. 459.

Overall, households living in compact developments can generally expect to use less energy than those living in sprawling areas; the heat island effect could amplify this impact. Translating residential energy use to CO_2 emissions is a straightforward undertaking, requiring only some additional information on the electricity generation fuel mix. This will be discussed along with other Burlington-specific data in the following section.

LOCAL-LEVEL DATA AND METRICS FOR BURLINGTON

The previous sections of this memo have discussed literature on the relationship between denser development (defined in various ways), VMT, and energy and CO_2. These sections are designed to illustrate the general state of understanding regarding these issues. In this section, we pull out the key points from the previous sections and apply them to the specific local context of Burlington. Our goals are twofold: first, to provide adjustment factors as needed for the numbers presented above; and second, to highlight the data sources and metrics available to local Burlington officials to use in tracking development-related energy and CO_2 impacts over time.

We note that Burlington's recently adopted Transportation Plan includes several progress indicators intended to track the City's performance over time. Some of these indicators could be particularly relevant for estimating energy and greenhouse gas impacts, including:

- Transit ridership (annual);
- Traffic volumes into and out of the City (vehicles per weekday);
- Transportation Management Association (TMA) Employee Mode Shares (percent walking biking, using transit, carpooling); and
- Energy Use/Greenhouse Gas Emissions (estimated fuel consumption in City, and by City residents by cars, trucks and buses).[60]

The Transportation Plan does not provide details on how this information will be collected.

Vehicle Miles Traveled

Theoretically, changes in the 'D' built environment variables (density, diversity, design, destination accessibility, and distance to transit) in the Burlington area should result in changes in VMT on the levels shown in Exhibit 1 above;[61] uncontrolled selection bias in the underlying studies may mean the observed effect will be somewhat smaller. There are a wide variety of ways in which these variables can be defined.[62] However, it appears that there are no data available tracking VMT on a sufficiently fine-grained scale for Burlington officials to compare residents and/or workers in the downtown/waterfront area to those who live and work farther away. Nor do there appear to be available data on the 'D' variables measured on a scale consistent with locally available VMT data. Consequently, officials will not be able to directly measure the impact of more compact development on VMT, unless Burlington undertakes new data collection efforts. Data collection efforts to track differences in VMT of residents in different areas of Burlington, or to track other 'D' variables, would likely be resource intensive undertakings, and would require public cooperation with new survey efforts. For these reasons, we do not recommend specific measures of the 'D' variables to track over time.

However, officials can examine data on travel patterns from the Bureau of Transportation Statistic's National Household Travel Survey (NHTS), the Census Bureau's annual American Community Survey, and local surveys of employee travel patterns by the Campus Area Transportation Management

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[60] City of Burlington Department of Public Works, Department of Planning and Zoning, and Community Economic Development Office 2011, p. 11.

[61] Ewing and Cervero 2010, p. 275. Note that this and other studies in this area evaluated urban areas much more populous in Burlington. It is unclear whether, due to Burlington's smaller size, the effects realized in Burlington from changes in development patterns may be greater or lesser than those noted in the general literature.

[62] See, e.g., Ewing and Cervero 2010, p. 267, and Ewing et al. 2008, pp. 67-68.

Association (CATMA). This approach should enable City officials to monitor the extent to which residents' travel behavior is changing over time as the cityscape changes.

The NHTS could prove to be a particularly rich data source, but it is updated relatively infrequently.[63] While the main body of the NHTS only reports nationwide data, states and metropolitan planning organizations (MPOs) can arrange for additional samples to be taken on a smaller geographic scale when the survey is being conducted. In 2009, the Chittenden County MPO and the Vermont Agency of Transportation partnered to purchase an additional sample of 1,690 households, of which 541 were in Chittenden County and the remainder elsewhere in the state.[64] Assuming that these organizations continue to purchase add-on samples in the future, area officials could have a substantial array of data available to track travel patterns over time.

While complete summary data from the Vermont NHTS sample were not readily available, a number of key statistics are reported in the 2010 Vermont Transportation Energy Report. Most importantly, this document reports VMT per capita at the county level; the figure for Chittenden County was approximately 9,500 VMT per person in 2009. Recall that Ewing et al. (2008) estimated that individuals could reduce their VMT by 20 – 40 percent by living in a compact development;[65] for Burlington residents, this would suggest a reduction of 1,900 – 3,800 VMT per person per year that moves from sprawling areas into compact developments.

The Vermont report also provides figures for average commute distance (9.1 miles for Chittenden County) and mode of travel to work (94 percent in automobiles, less than 1 percent by bus statewide; data not reported on a county level).[66] Based on the nationwide NHTS, it appears that survey data is also being collected for several other factors not listed in the Vermont Transportation Energy Report, including annual vehicle trips per person and per household, average trip length, and commute trip time, distance, and speed (reported separately for automobiles, transit, and walking).[67]

It will be several years before the next NHTS update is carried out. In the interim, Burlington officials may want to examine data from the Census Bureau's American Community Survey (ACS), which reports data on residents' means of transportation to work, place of work (i.e., in the county/state of respondents' residence), and average commute time. Note, however, that while means of transportation to work in particular could be quite useful, there is no clear way to translate travel time into travel distance without additional information. The ACS does not report on distance traveled to work or distances traveled for non-work purposes. Another potential data source consists of surveys conducted by local-level organizations. The existing Campus Area Transportation Management Association (CATMA) conducts surveys on its' employees commuting habits; a Downtown Transportation Management Association (DTMA) could presumably gather similar data for downtown workers.[68]

To measure environmental benefits associated with changes in Burlington's development patterns, officials should rely on direct survey measures of VMT, i.e., from subsequent updates to the NHTS (and from TMA surveys, to the extent they measure VMT or home-to-work distance). In percentage terms, officials can use the range of values noted previously in this memo to translate VMT into CO_2 emissions, namely, a 0.93 – 1 percent drop in CO_2 for every 1 percent decrease in VMT. In absolute terms, the

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[63] Prior to the 2009 NHTS, the four previous surveys were conducted in 2001, 1995, 1990, and 1983.

[64] University of Vermont Transportation Research Center. "NHTS (National Household Travel Survey) Vermont. 2011. http://www.uvm.edu/~transctr/?Page=nhts_default.php&SM=_researchmenu.html

[65] Ewing et al. 2008, p. 9.

[66] University of Vermont Transportation Research Center. "The Vermont Transportation Energy Report: Vermont Clean Cities Coalition." TRC Report # 10-0017. August 2010, pp. 13-15. http://www.uvm.edu/~transctr/cleancty/pdf/UVM-TRC-10-017.pdf

[67] Department of Transportation Federal Highway Administration. "Summary of Travel Trends: 2009 National Household Travel Survey." FHSA-PL-11-022. June 2011. http://www.uvm.edu/~transctr/cleancty/pdf/UVM-TRC-10-017.pdf

[68] City of Burlington Department of Public Works, Department of Planning and Zoning, and Community Economic Development Office, 2011

average passenger vehicle gets 20.8 miles per gallon (i.e., it uses 1 / 20.8 = 0.048 gallons per mile) and emits 19.4 lb. CO_2 per gallon gasoline; this translates into average emissions of 0.93 lb. CO_2 per mile.[69] Thus, every one VMT decreased should result in a net decrease of 0.86 – 0.93 lb. CO_2.

Data on commute modes alone (i.e., ACS data) will not be sufficient to estimate VMT. However, the environmental benefits of shifts from automobile to public transportation use, which can be observed in ACS data, can be estimated in the manner described below.

Public Transportation

The Chittenden County Metropolitan Planning Organization's Long Range Regional Transportation Plan calls for a tenfold increase in use of public transportation over a 20-year span, from 0.6 to 6 percent of all trips taken. Chittenden County estimated that 2.4 percent of all trips would be taken by transit in 2010.[70] Clearly, there is an expectation that transit could play a significant role in Burlington's transportation future. If this is realized, there are multiple ways in which Burlington could estimate environmental benefits from public transportation.

The Chittenden County Transportation Authority (CCTA), which runs the bus system in the Burlington area, reported a total of 2,455,730 riders in its fiscal year 2010. This number has been trending generally upward in recent years, albeit with a slight decrease from 2009 – 2010. All CCTA buses use diesel fuel and average between 3.5 and 6 miles per gallon (mpg).[71] The overall fleet averages about 4.27 mpg.[72]

The CCTA also tracks the total number of miles driven and the total quantity of fuel used by all of its buses (1,589,359 miles and 372,534 gallons in FY 2011).[73] It is unclear whether the CCTA gathers data on the distances traveled by individual passengers; at least an estimate of distances would be necessary to calculate the agency's total passenger-miles (a key parameter in estimating relative environmental impacts). As described above, comparing CCTA's fuel used per passenger-mile (i.e., total fuel use divided by total passenger-miles) to results using typical passenger vehicles reveals the net environmental benefit per person from the CCTA transit system. Since the 'average' car carries 1.6 people at any given time, the nationwide average of 20.8 mpg would translate into 1 / (20.8 x 1.6) = 0.03 gallons per person-mile for passenger vehicles. The fuel used per passenger-mile by CCTA buses should be subtracted from this figure to produce a net reduction per person-mile. As noted above, the 'average' bus would need to carry about 11.7 people at all times to produce an efficiency gain.[74] To translate levels of fuel use into CO_2 emissions, we must apply fuel emissions factors. As reported earlier, EPA estimates CO_2 emissions from gasoline at 8,788 grams (19.4 lb.) per gallon, and 10,084 grams (22.2 lb.) per gallon for diesel fuel.[75]

Burlington could calculate environmental gains from public transportation as shown in Exhibit 2.

[69] Moore et al. 2010, p. 571, and Department of Energy Center for Transportation Analysis 2010.

[70] City of Burlington, Vermont. "2006 Municipal Development Plan." Adopted May 22, 2006. http://www.ci.burlington.vt.us/planning/comp_plan/municipal_development_plan/2006/mdp_2006_complete_burlington_vermont.pdf

[71] Data provided by Jon Moore, Chittenden County Transportation Authority. Personal correspondence with Sandrine Thibault, Department of Planning & Zoning, City of Burlington. July 6, 2011.

[72] Data provided by Jon Moore, Chittenden County Transportation Authority. Personal correspondence with Sandrine Thibault, Department of Planning & Zoning, City of Burlington. July 19, 2011.

[73] Ibid.

[74] Moore et al. 2010, p. 571, and Department of Energy Center for Transportation Analysis 2010.

[75] Environmental Protection Agency, 2005.

EXHIBIT 2: CALCULATING ENVIRONMENTAL GAINS FROM PUBLIC TRANSPORTATION

ROW	CALCULATION STEP	CURRENT VALUE	DATA SOURCE
[1]	Total Bus Gallons (Diesel) Consumed	372,534	CCTA
[2]	/ Total Bus Passenger-Miles	Unknown	CCTA
[3]	= Bus Gallons (Diesel) per Person-Mile	[1] / [2]	Calculated
[4]	x CO_2 per Gallon (Diesel)	22.2 lb.	EPA
[5]	= Bus CO_2 per Person-Mile	[3] x [4]	Calculated
[6]	Automobile Gallons (Gasoline) per Person-Mile	0.03	U.S. Average
[7]	x CO_2 per Gallon (Gasoline)	19.4 lb.	EPA
[8]	= Automobile CO_2 per Person-Mile	[6] x [7] = 0.582 lb.	Calculated
[9]	Net CO_2 Reduction per Passenger-Mile from Riding Bus	[8] – [5]	Calculated
[10]	Total CO_2 Reduction from Riding Bus	[9] x [2]	Calculated

Note that performing the above exercise for each bus route individually, rather than for the system as a whole, would facilitate an analysis of specific routes that net the most energy savings.

Building Energy Use

Burlington's electricity is provided by the Burlington Electric Department, a public utility. The utility also owns much of the electricity generation used to provide power to the town. It appears that the utility does not routinely track electricity consumption for the downtown/waterfront area separately from the rest of its service area; thus, it will most likely not be feasible to directly measure changes in consumption due to denser development. However, the utility does track average consumption by rate class. At present, area residential consumers use an average of 5,190 kWh of electricity annually, while commercial customers use an average of 51,806 kWh. [76]

A number of residences and businesses in Burlington rely on natural gas for heating and other purposes. As with the Electric Department, the local gas utility, Vermont Gas, does not track average use on a neighborhood scale. Vermont Gas reports average residential consumption of 900 ccf of gas per year; commercial use varies widely depending on the type of establishment, so that overall averages are not as meaningful.[77]

Other homes rely on oil; 1.7 million homes across New England (excluding Massachusetts) used fuel oil for space heating in 2009, roughly twice as many as used natural gas.[78] However, fuel oil data is not collected at the local level, so we cannot readily estimate or track levels of consumption in Burlington.

While it would be difficult to establish a clear causal link between Burlington's land use policies and building energy use, we recommend that City officials continue to track these average consumption figures to determine whether any observed changes in developmental density that occur over the next several years are correlated with lower consumption. Applying the generic findings noted above, Burlington residents that move from a typical detached single-family home to a smaller detached home would save on the order of 4.4 percent of their total electricity and natural gas use; moving to an apartment could expect to save 20 – 37 percent. Using Burlington's levels of consumption, this would translate to savings 228 kWh electricity and 40 ccf natural gas for a smaller detached home (worth about $92 at current retail rates), or 1,038 – 1,920 kWh electricity and 180 – 333 ccf gas for an apartment

[76] Burns, Chris. Burlington Electric Department. Personal correspondence with Sandrine Thibault, Department of Planning & Zoning, City of Burlington. June 28, 2011.

[77] Harrington, Scott. Vermont Gas. Personal correspondence with Shelly Martin, Spring Hill Solutions. June 29, 2011.

[78] Department of Energy, Energy Information Administration. "Residential Energy Consumption Survey, Table HC1.8: Fuels Used and End Uses in Homes in Northeast Region, Divisions, and States, 2009." 2011. http://www.eia.gov/consumption/residential/data/2009/#fueluses

(worth about $414 – $766).[79] Because Burlington has more heating degree days than cooling degree days, the savings realized may be slightly greater if the heat island effect is of sufficient magnitude.

Calculating CO_2 savings from reductions in natural gas use is straightforward; burning one ccf natural gas emits about 12 lb. of CO_2.[80] To calculate the carbon impact of electricity use, we must evaluate the mix of fuels used to generate electricity in the area. According to EPA's eGRID database, Vermont averaged just 0.00342 lb. CO_2 per kWh electricity generated in 2007, by far the lowest rate in the nation; this was due to the state's near-total reliance on nuclear, hydro, and biomass for electricity generation.[81] However, the Burlington Electric Department reports a considerably less favorable emissions profile after adjusting for short-term electricity purchases and sales of Renewable Energy Certificates, in which the unbundled electricity is assigned the characteristics of the New England residual fuel mix. Accounting for these factors, the utility's fuel mix in 2010 was 24.35 percent natural gas, 6.63 percent coal, 4.22 percent oil, and the remainder nuclear and renewables.[82] Using average emissions rates from EPA,[83] this would mean that Burlington consumers are actually emitting 0.497 lb. CO_2 per kWh electricity.[84]

Summary of Local Data and Metrics for Burlington

In summary, we recommend that Burlington officials use the following estimates and metrics to communicate the prospective climate-related benefits of compact development, and to measure the city's performance over time.

[79] See https://www.burlingtonelectric.com/page.php?pid=11&name=residential_rates and http://www.vermontgas.com/residential/res_rates.html

[80] Environmental Protection Agency. "Compilation of Air Pollutant Emission Factors. Volume I: Stationary Point and Area Sources." AP-42, Supplement D: Chapter 1.4, July 1998. P. 1.4-6. http://www.epa.gov/ttn/chief/ap42/ch01/final/c01s04.pdf

[81] Environmental Protection Agency. eGRID2010 database Version 1.1. May 20, 2011. http://www.epa.gov/cleanenergy/energy-resources/egrid/index.html

[82] Burlington Electric Department. "Power Supply: BED's Power Supply for 2010." July 14, 2011. https://www.burlingtonelectric.com/page.php?pid=128&name=BED%27s%20Power%20Supply

[83] Environmental Protection Agency. "Clean Energy: Air Emissions." December 28, 2007. http://www.epa.gov/cleanenergy/energy-and-you/affect/air-emissions.html

[84] EPA's emissions factors are 1.14 lb. CO_2 per kWh natural gas, 2.25 lb. per kWh for coal, and 1.67 lb. for oil. Thus, (1.14 lb./kWh x 0.2435) + (2.25 lb./kWh x 0.0663) + (1.67 lb./kWh x 0.0422) = 0.497 lb./kWh.

EXHIBIT 3: SUMMARY OF LOCAL-LEVEL METRICS FOR BURLINGTON

GENERAL ENVIRONMENTAL BENEFIT	BURLINGTON BASELINE DATA	POTENTIAL BURLINGTON ENVIRONMENTAL BENEFIT	BURLINGTON DATA SOURCE
20 – 40 percent household-level VMT reduction from compact development	9,500 VMT per person per year (total)	1,900 – 3,800 VMT per person per year	Chittenden County/Vermont NHTS add-on sample
	0.86 – 0.93 lb. CO_2 per VMT	1,634 – 3,534 lb. CO_2 per person per year	N/A (value from literature)
Total CO_2 reduction from bus ridership	Unknown	Calculated per Exhibit 2	CCTA
4.4 percent residential energy savings from moving from a larger detached home to a smaller detached home	5,190 kWh electricity per residence per year (total)	228 kWh electricity per residence per year	Burlington Electric Department
	0.497 lb. CO_2 per kWh	113 lb. CO_2 per residence per year from electricity	Burlington Electric Department (fuel mix); EPA (emissions factors)
	900 ccf gas per residence per year (total)	40 ccf gas per residence per year	Vermont Gas
	12 lb. CO_2 per ccf gas	480 lb. CO_2 per residence per year from gas	N/A (value from literature)
20 - 37 percent residential energy savings from moving from a larger detached home to smaller apartment	5,190 kWh electricity per residence per year (total)	1,038 – 1,920 kWh electricity per residence per year	Burlington Electric Department
	0.497 lb. CO_2 per kWh	516 – 954 lb. CO_2 per residence per year from electricity	Burlington Electric Department (fuel mix); EPA (emissions factors)
	900 ccf gas per residence per year (total)	180 - 333 ccf gas per residence per year	Vermont Gas
	12 lb. CO_2 per ccf gas	2,160 – 3,996 lb. CO_2 per residence per year from gas	N/A (value from literature)