TRANSPORTATION AND LAND USE SOLUTIONS FOR LOW-CARBON CITIES

Kara Kockelman
Professor and William J. Murray Jr. Fellow
Department of Civil, Architectural and Environmental Engineering
The University of Texas at Austin
6.9 E. Cockrell Jr. Hall
Austin, TX 78712
kkockelm@mail.utexas.edu

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ABSTRACT

This paper summarizes widely discussed (and often debated) policies and design strategies used to reduce greenhouse gas (GHG) emissions through changes in land use, the built environment and transportation system management, vis-à-vis travel choices. Anticipation of design and policy impacts should prove helpful as cities grow. For example, densification facilitates carbon-saving reductions in trip lengths along with beneficial mode and vehicle ownership shifts, while moderating numerous other problems associated with sprawl. However, lower speeds result in much lower fuel economies, per mile traveled, while delaying travel. Policies like roadspace and vehicle rationing or taxes and tolls with credits and feebates can greatly mitiage the potential congestion, emissions, and travel delay issues.

INTRODUCTION

Greenhouse gas (GHG) emissions are impacted by land use conditions in numerous ways, from vegetative cover practices to parking polices, and compact development patterns to self-selection in location choice. While land use is relatively slow to change, its relative permanence has a marked impact on long-term concerns, like climate, economic opportunity, access, and equity, as travelers and goods determine how best to navigate between sites of production and consumption, residence, and out-of-home activities. Land development decisions determine activity site locations, which are fundamental to rates of trip generation and attraction, thereby impacting travel distances, mode choices, and vehicle ownership decisions. Such choices have short- and long-term ramifications for climate, air quality, energy security, crash-related death tolls, access, economic opportunity, and quality of life.

In general, land development decisions impact transport choices more directly than the reverse (from travel to land use), thanks to trip generation and attraction rates, which are key predictors of overall regional and inter-regional travel (Zhao and Kockelman 2002). Nevertheless, transport infrastructure investment decisions can be critical to various development decisions, particularly in locations starting with relatively poor or no access, which may characterize many regions within developing countries. In reality, land use-transport interactions can be intense when growth is rapid, as it is in places like China and India.

While some countries have no private land ownership (like China) and some have strong regional control of land release to developers (like Canada and many European countries), many (like the U.S.) have opted for a more laissez faire approach. In fact, some highly developed regions, like Houston, Texas, offer almost no zoning controls on siting of different land use types. Such controls emerged during the Industrial Age to separate noxious uses (like polluting industry) from residences (and other sensitive sites). In many cases, such zoning controls have resulted in a greater separation of trip generators and attractors than New Urbanists and others in the planning profession recommend; separation of land uses tends to increase travel distances and favor the faster automobile mode (over non-motorized modes and transit). Such land use patterns endure for 100 years or more, in many cases (with residences having lifetimes on the order of 100 years, and commercial structures often being razed after about 50 years).

Long ago U.S. policies ensured division of land use management decisions (as handled by local cities) and transportation investment decisions (handled by state departments of transportation, with some input by metropolitan planning organizations). Separating control of these intimately related processes has resulted in largely uncoordinated choices and imperfect transportation and land development policies across the U.S. Transportation agencies, eager to tame congestion and meet ostensible travel demand, dramatically expanded highway systems, rather than seeking a mode-balanced and land-use-balanced set of accessibility improvements (Bartholomew 2007, Litman 2003 and 2007, Handy 1994). Ideally, transportation engineers and planners should recognize how their decisions impact access to jobs, schools, services, and other key destinations via a variety of modes, along with longer-term land use changes. In reality, various highway improvements can degrade access for local travelers, including walk and bike modes, and quality of life for local residents and shop owners, while improving travel times for through travelers. Such myopic planning led to America‘s Freeway Revolts of the 1960s and 1970s (Mohl 2004).

Transport is responsible for roughly 30 percent of U.S. GHG emissions (EIA 2010), and 67 percent of the nation‘s refined-petroleum consumption (BTS 2010). The U.S. houses only 5% of the Earth‘s population yet owns 33% of its cars and contributes 45% of global vehicle emissions (Ewing 2007b). A variety of modes contribute to U.S. transportation emissions, including light-duty vehicles, heavy-duty trucks, air, shipping, and rail, which contribute 62%, 19%, 9%, 3%, and 2%, respectively (EPA 2006b). Transportation GHG reduction paths include lower carbon intensity vehicle fuels, improved fuel economy, and travel demand management (via, for example, mixed land uses, road pricing, improved logistics, and more restrictive parking policies) to reduce energy use directly, moderate travel distances, and shift travel to more efficient modes.

Transport accounts for more than 40-percent of the average household‘s home-based energy requirements (Walker and Rees 1997, Harmaajarvi et al. 2002). Such numbers suggest that significant energy savings may result from a variety of changes, including more compact development (due to shortened travel distances, for household members, visitors, and deliveries). By shifting the vehicle fleet to plug-in vehicles and thereby electric power sources, travelers have an incredible opportunity to reduce their carbon footprints (depending on power plant feedstocks [e.g., coal versus natural gas, wind and solar]). By raising fuel economy standards and exploiting hybrid-electric-vehicle (HEV) and various engine technologies (e.g., high-compression ignition), policymakers and auto manufacturers have a terrific opportunity to reduce transport energy needs.

Though it generally is much easier to change travel habits (including vehicle choices) than to change urban form, particularly in the short term (thanks to pricing and parking policies), many studies describe meaningful impacts from land use policies and thoughtful urban planning. For example, Ewing and Cervero‗s (2001, 2010) comprehensive reviews of studies suggest that regional-level access to one‗s home location is a key predictor of a household‗s vehicle-miles, while vehicle ownership and mode choices are more influenced by neighborhood-level attributes. As Boarnet and Crane (2001) note, however, the behavioral processes at play are complex, and the use of different data sets and geographic scales and model specifications generally results in somewhat distinct conclusions.

This paper examines the impact of land use on travel and transport patterns. Travel demand management policies such as congestion pricing, mode subsidies, and parking policies also play an important role in reducing GHG emissions.

TRAVEL IN THE U.S. AND CHINA

While land use is a key factor behind transport choices, demographics are even more important. (see, e.g., Schimek [2006] and Zhao and Kockelman [2002]). Vehicle registrations are soaring in China, thanks to, increased commercial penetration, and what is likely an increasing perception of an international lifestyle in which a car ownership may seem essential (Gakenheimer 1999). In 2007, China surpassed the United States as the single largest contributor of GHG to the atmosphere (Sperling 2009).

There is a distinct urban/rural split in China‗s personal vehicle ownership. By 2020, over 80% of China‗s private vehicles are expected to be in use in urban areas, with cities contributing 77% of that nation‗s vehicle emissions (Han 2007). The percentage of cars per 1000 people in developing countries correlates with the percentage of population in urban areas – which, in turn, is a surrogate for income, because the majority of people in developing countries who can afford automobiles live in cities (Gakenheimer 1999). China has 86 cities with population over more than 750,000 (Sperling 2009), and cities like Shanghai are purposefully shifting jobs and population away from the urban core, building satellite cities to house its residents. As distances between workers and jobs increases, cars become more useful – and more difficult for transit, walking and biking to compete with (Sperling 2009).

U.S. planners are grappling with the results of a long-term, somewhat single-minded focus on car and truck ground transportation; bike lanes and pedestrian corridors are the calling cards of change for progressive U.S. cities, but the monoculture of highway infrastructure has created a challenging built environment, often hostile to non-motorized travel. China‗s 20th Century status as the ―Bicycle Kingdom‖ (Liu 2004) is an example of how dense development with short distances between home, school and business can moderate GHG emissions. The emphasis on bicycles, however, has been a topic of debate in China, as bicycle traffic impacts roadway congestion and safety, and longer-distance bicycling may not be practical in most settings. (Liu 2004)

One way to moderate vehicle use is by directly limiting sales, as done via restrictive auctions in Singapore. Vehicle registration taxes are a far more common tool, but offer policymakers much less control over vehicle sales numbers. Hong Kong's travel demand management policies include a vehicle registration tax of 35% to 100% of vehicle cost. This tax has been credited with maintaining private automobile ownership rates at about 50 private cars per 1,000 persons in 2004 (Tang 2008), in contrast to 765 cars per 1,000 Americans (UN Data 2010). Private cars accounted for just 10% of daily passenger journeys in Hong Kong in 2003 (Tang 2008), versus roughly 90% in the U.S. (and over 80 percent of U.S. person-trips of just 5 miles or less in distance).

LAND USE AND TRANSPORT

As a derived demand, travel ensures that persons can engage in various activities at multiple sites, while packages and products reach their intended distributors and end users. Whether they be homes or businesses, parks or croplands, the more separated in space these activity sites are, the longer the travel distances. Accompanying these distances is a shift to faster modes, an infeasibility of non-motorized modes, and greater demand for high-speed freeways and jet airplanes. Within a given transportation system, greater distances caused by greater populations or less intensely developed land will result in greater demands on system components and a higher likelihood of congested travel conditions, over land, over water, and in the air. It is important that community planners and system designers recognize this.

Travel is a complex phenomenon: travelers trade off alternative destinations and routes, modes, vehicle ownership levels, and their own home (and work and school) locations. Thus, regions with double the density of activity sites (proxied by work and population densities) generally will not experience half the amount of travel distance or travel-related energy consumption, even though transit and carpooling may become more viable alternatives.

The Effects of Land Use Density

As discussed in Kockelman and Zhao (2011), low-density land use patterns have been characterized as an important source of roadway congestion, energy depletion, air pollution, and GHG emissions (see, e.g., Dunphy and Fisher [1996], Newman and Kenworthy [2006] and Ewing et al. [2008]). Many conclude that vehicle ownership levels, motorized trip shares, and vehicle miles traveled (VMT) depend on various features of urban form in both practically (and statistically) significant ways. (See, e.g., Fang [2008], Holtzclaw et al. [2002], Ewing and Cervero [2001 and 2010] and Cervero and Kockelman [1997].)

Kockelman and Wang (2011) describe how regressions of vehicle ownership levels on demographic and land use attributes at the level of traffic analysis zones (TAZs) in Austin, Texas, signal a striking 30 percent elasticity with respect to local employment density, ceteris paribus, suggesting that jobs density (or the attributes for which it proxies, such as regional access, central location, and land use balance) can play a key role in energy and VMT savings, per capita (Musti and Kockelman 2009). Moreover, as the distance to the region‗s central business district (CBD) falls in such regressions, vehicle ownership falls further, providing a type of ―double dividend‖ (since many jobs tend to be centrally located). Since VMT per vehicle owned is relatively stable, regardless of vehicle ownership level (averaging 9,000 to 10,000 miles per year, in the United States, according to National Household Travel Survey data [Kockelman et al. 2009]), much of the VMT and energy savings that can come from land use changes probably stem from vehicle ownership decisions.

Newman and Kenworthy (1996, 1999, 2006), Holtzclaw (1991, 1994), and Holtzclaw et al. (2002) are regularly cited on the question of VMT versus population and jobs densities. As Kockelman and Zhou (2011) explain, ―One may expect an elasticity of regional VMT with respect to regional density of about 25 to 30 percent. In other words, as density doubles, energy use and VMT tend to fall by 25 to 30 percent. Or, as density halves, energy use and VMT have been estimated to rise by over 30 percent—even after controlling for certain demographic attributes like income and household size (Holtzclaw et al. 2002). Nevertheless, a wide variety of other attributes—including parking costs, land use balance, infrastructure provision, demographics, and even topography—can be critical. All are at play in the land use-transport connection, and density in isolation is no panacea for congestion and many other transportation problems.‖

Holtzclaw et al.‗s (2002) reliance on vehicles‗ odometer readings in San Francisco, Chicago, and Los Angeles resulted in elasticity estimates of the effects of neighborhood population density on household vehicle ownership and VMT to lie between -0.32 and -0.43, on par with Newman and Kenworthy‗s (1999, 2006) estimates for gasoline consumption levels across world cities. Of course, this sample of three U.S. cities enjoys above-average transit systems (for the U.S. context) and relatively high household incomes (for the global context), and Holtzclaw et al.‗s model did not control for parking costs, household income, and several other relevant variables; so extrapolation to other contexts may yield different results. Moreover, while higher densities also favor smaller, more fuel-efficient cars, they often come with more congested travel conditions and more use of motorized transit; so it is not clear whether GHG emissions will fall by these same percentages when density doubles.

As Kockelman and Zhou (2011) note, Newman and Kenworthy‗s (2006) estimate that 35 jobs and/or persons per hectare (14 per acre) serves as something of a key threshold density for per-capita transport energy use. ―Above this density they notice a sharp reduction in walk, bike, and transit. Based on the idea that the average person will spend one hour traveling every day, they estimate that at least 10,000 residents plus jobs need to be provided within a ten-minute walk time radius (approximately 0.8 to 2.0 square miles, based on 3 to5 mi/h walking speeds) and 100,000 residents plus jobs in a 30-minute walk time radius for adequate amenities to be provided without auto dependence to support them. They suggest that it is unrealistic for cities to simply add a rail line through the center and expect significant distance and mode shifts, but any auto-oriented city could be restructured as smaller, transit-oriented cities. While these numbers are encouraging, some suspect the results may be a result of statistic techniques used and the data sets/contexts analyzed, rather than a fundamental relationship between population/employment densities and VMT (Brindle, 1994). Essentially, different cities around the world enjoy very different histories, cultures, incomes, and transport systems. Moreover, the notion of regional density relationships holding at the local level is quite problematic.‖

Cervero and Kockelman (1998) examined many features of urban form that may reduce auto dependence. Their gravity-based accessibility measure for access to commercial jobs was found to have an elasticity of -0.27, suggesting neighborhood retail shops and pedestrian-oriented design are more significant than residential densities in mode choice selection. Integrating aspects of pedestrian-oriented design such as four-way intersections and vertical mixing of land uses may result in significant VMT reductions. For example, a 10% increase in the number of four-way intersections in a neighborhood was associated with an average reduction in VMT of 384 miles per year per household.

Equally important to the understanding of how these factors may reduce VMT is an understanding of what factors individuals most prefer in neo-traditional developments. In Lund‘s (2006) survey where California residents were asked to identify their top three reasons for choosing to live in a TOD, only 33.9% cited transit accessibility as a top reason. More often, residents preferred type or quality of housing (60.5%), cost of housing (54%) or quality of neighborhood (51.7%). Lund (2006) also found that residents who listed transit as one of their top three reasons were 13 to 40 times more likely to use transit than those who did not, suggesting the effects of self-selection in such developments may be significant.

The advantages of compact development are synergistic in many respects. With more locations closer to home, one may choose to walk or bike to their destination, reducing fuel use. The fact that buildings are closer together also has great impacts on public service infrastructure and a municipality‘s ability to provide water, electricity, and emergency services. By shifting 60% of new growth in the U.S. to compact patterns, Ewing et al. (2007b) estimated that the U.S. could save 85 million metric tons of CO2e annually by 2030, a savings roughly equivalent to a 28% increase in vehicle efficiency standards by 2020. Such compact development will also slow the growth of urbanized areas which currently are growing three times faster than urban populations and preserve the nation‘s forest and farmland.

Cervero and Kockelman (1997) examined urban design strategies that could be implemented in the nearer term. A 10% improvement in walking quality (defined on the basis of variables like sidewalk and street light provision, block length, planted strips, lighting distance and flatness of terrain) could yield a 0.09% reduction in SOV travel for non-work trips, corresponding to a reduction of 33 pounds of CO2e per household per year. When the impacts of walking quality on private car use are factored in, a household‘s annual VMT savings is potentially 819 miles. The reduction in SOV trip by improving land use mixing, through diversity within an area as well as surrounding areas, a household could reduce CO2e by 41 pounds per year. The greatest effect on travel from such urban design strategies is associated with the number of four-way intersections. Such intersections tend to enhance network connectivity, thereby facilitating (via shortening) walk and bike trips. If one accepts these estimates, a 10% increase in four-way intersections with 1% of households in a neighborhood conforming to the expected behavior is associated with annual CO2e reductions of 384 pounds per household.

Related to all of this is the notion of transit-oriented development (TOD), which is defined as an area with moderate to high residential density with employment opportunities and shopping within easy distance to transit stops. Such development resembles ―traditional cities‖ and allows reductions in driving by increasing a neighborhood‘s ―walkability‖ through higher densities and shares of four way intersections, a more connected grid pattern for streets, and wider sidewalks. Nevertheless, some (e.g., Brindle 1994, Schimek 1996, Shoup 1997) argue that economic factors (such as income and parking costs) are the primary forces behind transportation choices. And others worry that self-selection[1] has a significant role to play, offsetting perhaps half of the reputed travel-related benefits of compact form.

Taking a look at the literature across a hundred or more popularly discussed carbon-saving policies for the U.S., Kockelman et al. (2009) concluded that the impacts of urban form are moderate to slim. This seems particularly true when land use strategies are compared to other GHG-reducing policies, as shown in Figure 1‘s bar heights (where only the Top 20 strategies evaluated are shown). Moreover, in most cases, land use changes require a long time to take effect (thanks to the longevity of existing buildings, entrenched expectations of property owners in existing neighborhoods, and so forth). Nevertheless, such options can make very good sense for new neighborhood and city designs, if done thoughtfully. Beyond climate change (and energy security) concerns relating to transportation directly, communities tend to face great infrastructure and maintenance cost implications from sprawling land use patterns (e.g., extending power, water and sewage lines, building detached homes with individual garages on parcels that need regular landscape maintenance) and a high degree of automobilization (with highways generally costing much more per traveler-mile served than bikeways and sidewalks, for example). A reliance on automobile travel also results in a high number of deadly crashes (taking more lives of persons under age 35 than any other factor in the U.S. and presumably many other developed countries) and an appreciable loss in human fitness (characterized by growing obesity issues and heart disease [a top killer] in many developed countries, but particularly pronounced in the U.S.). Air quality is diminished, noise levels rise, and quality of life is can suffer quite noticeably. Fortunately, there are many regions of the world still growing rapidly (such as China), where land use controls are strong and planners and policymakers can have a major impact on development patterns. There also are reasonably effective transport policies that offer more immediate and pronounced GHG savings than land use patterns generally can, as well as health and quality of life benefits, as described below.

TRAVEL DEMAND MANAGEMENT

Travel demand management (TDM) strategies with potential to abate transportation GHG emissions include shifting travel to more efficient modes and operating contexts (e.g., off-peak times of day) and reducing overall passenger travel. These strategies typically use existing assets thus avoiding the cost or time-lag of new technologies, but institutional and attitudinal challenges must still be confronted.

Impacts of Pricing

[1] While definitive conclusions have not emerged, general neighborhood design distinctions appear responsible for at least half of the observed VMT differences. (Please see Cao et al. [2006], Mokhtarian and Cao [2008], and Zhou and Kockelman [2008] for discussions of literature and results in this area.)

Pricing strategies send market signals which reflect the true costs of driving. As noted earlier, government-imposed pricing may be in the form of registration or other ***vehicle-ownership fees***. ***Gas taxes*** are common everywhere, but some are too low to be effective as a demand management tool. In these U.S. (federal and state), for example, such taxes contribute just 40 cents per gallon to the price of gasoline, on average (EIA 2008a). Petrol taxes are significantly higher elsewhere (e.g. roughly 2 to 3 times higher throughout much of the European Union [IEA 2008]). They diminish demand for gasoline either via reduced driving (via carpooling and other mode shifts, closer destination choices, tele-commuting and the like) and/or improved fuel efficiency (Puller and Greening 1999). A recent estimate places the own-price elasticity of demand for gasoline at just -3.4 to -7.7 percent (Hughes et al. 2008), largely because fuel is a relatively small component of vehicle ownership and use costs, and trip destination choices (like work, school, and home) and vehicle ownership attributes (number and type or fuel economy of vehicles owned) are difficult to change in the near term. In the longer run, such demand elasticities are higher, possibly -0.25 to -0.4. Either way, carbon taxes (which come to just $0.625 [USD] per gallon at $50 per ton of $CO2_e$) are unlikely to inhibit much travel. And there is always the rebound effect: perhaps 10 to 20 percent of fuel savings due to a shift to more efficient vehicles is estimated to be ―lost‖ to more driving (thanks to lower fuel costs per mile traveled [Small and van Dender 2007]).

Congestion pricing of roadways presents a valuable opportunity to rationalize road networks, by helping ensure that travelers pay for the delay costs they impose on others (essentially those traveling behind them [see, e.g., Kockelman 2011]). A recent study of Seattle, Washington travelers with GPS vehicle units estimated that variable network pricing (to reflect the congestion impacts of different demand levels over space and time) would reduce that region‘s VMT by 12% and total travel time by 7% with a 6-to-1 benefit-cost ratio (PSRC 2008). The policy approach vetted was very similar to Kockelman and students‘ credit-based congestion pricing policy proposals (Kalmanje and Kockelman 2004, Kockelman and Kalmanje 2005, Gupta and Kockelman 2006, Gulipalli and Kockelman 2008). However, their VMT results from network simulations of the Austin and Dallas-Ft. Worth regions of Texas do differ. In the Texas cases, marginal social cost pricing of freeways or all links by time of day was rather consistently estimated to result in VMT savings of under 10 percent. Nevertheless, if road pricing of some form were to reduce U.S. VMT by 12 percent for 1 percent of all drivers, the total CO2e emissions savings is estimated to be 1.69 million metric tons, or 0.023% of the US total.

Priced parking can be an effective travel demand reduction because it overcomes the temporal lapse between costs drivers pay and when they decided to travel. Elasticity estimates for travel demand with respect to parking prices range from -10 to -30 percent, with variation due to numerous factors including trip purpose, location of parking, availability of substitute modes or other free parking, and price and fee structure (e.g. hourly, first hour free, etc.).

Provision of Parking

Like the price of parking, space provision policies can have a significant impact on VMT if enough alternatives to driving are provided. Many cities have created guidelines requiring a minimum number of places per establishment or dwelling unit, but are now finding that an effective way to reduce congestion and pollution is to reduce available parking, or charge premium prices for it. TCRP (2004b) researchers found that by eliminating such requirements and charging market rates for residential spaces could potentially reduce vehicle ownership per household (along with VMT per vehicle, to some extent), enough to reduce household VMT by 30%. This elasticity suggests that, if 1% of households residing in multifamily units were charged $50 per month for parking in the U.S., U.S. transport GHG emissions would fall by 0.054% (Kockelman et al. 2009).

The goal of minimum parking requirements is to meet recurring peak demands. In effect, planners identify the highest number of vehicles parked at an existing location and then require developers to supply at least that many spaces for future parking at similar land use, disabling travel demand management opportunities at the parking stage. Shoup (1997) argued that, since such base demands do not account for price, nowhere in the planning stages is cost accounted for, making car ownership more affordable. ―Free‖ parking (along with government subsides of highway facilities) thus has impacts on vehicle trip generation.

Cruising for a parking space can be responsible for a significant portion of a downtown area‘s traffic. In 2006, studies in Manhattan and Brooklyn found that vehicles looking for an on-street parking space accounted for 28 and 45 percent of traffic, respectively (Shoup 2007). This is because curb parking may cost $1 an hour in the U.S., while CBD-area garage parking can cost as much as $20 an hour. The cost of underground parking can easily reach $22,000 or more, per space (Shoup, 1997), sometimes costing more than the car that will be parked in it. Shoup (1997) calculates that a $23,600 parking space effectively costs $91 per month[2]. At this price, providing four parking spaces per 1,000 square feet of office space will make parking costs nearly 40 percent of total building construction costs, including parking. In most cases, individuals do not pay the $91 per month to park, rather their employer or retailers offer such benefits. Shoup (1997) estimates that such parking subsidies exceed a vehicle‘s operating costs and skew mode choice towards private automobile. If drivers were charged for parking based on the size of their vehicle, they may be more likely to purchase smaller cars. Just as one example: two Smart Cars can be parked in one conventional parking space, thereby presumably halving one‘s parking costs and promoting purchase of a much more fuel-efficient (and less crash aggressive) vehicle.

Shifting Modes

Mode shifts away from the single-occupant private car typically reduce GHG emissions by using energy more intensively (per traveler or per occupied-seat mile), thus emitting lower GHG per passenger-mile (pax-mi). Increased reliance on public transport systems can also facilitate adoption of alternative fuels and technologies to improve vehicle efficiency (thanks to economies of scale in production, from heightened demand). The baseline for mode shifts here is private vehicle travel, which accounts for the majority of passenger travel in many developed countries (e.g., NHTS 2001).

According to Kockelman et al.‘s (2009) review of the literature, among simply having two persons on board a private vehicle can render this the most efficient mode (in terms of $CO2_e$ per

[2] This estimate assumes an underground parking structure, zero land cost and property taxes, a 50-year life, and 4% discount rate (Shoup 1997).

passenger-mile served). Average U.S. automobile occupancy is only 1.63 passengers, and occupancy is even lower for certain crucial trip types (e.g. 1.14 passengers for home to work trips). At average occupancies, rail transit tends to outperform driving (i.e., offer lower carbon emissions per person-mile traveled), while buses and driving are roughly equivalent (on a Btu/pax-mi basis). Rail savings generally depend upon the carbon intensity of the electricity they run on and could fall with improvement in electricity generation. Buses, if running at low occupancies, actually result in a GHG emission increase; an occupancy slightly higher than average is needed to make buses less CO_2 intensive than driving, though running buses on alternative fuels can change this. Moreover, to the extent that bus use encourages walking and shorter trips (in order to access bus stops and reduce bus travel times) and more clustered land use patterns (to reduce access costs and trip distances), a one-to-one passenger-mile comparison is imperfect. Of course, much underutilized capacity exists on alternative modes, so a more accurate illustration of the GHG savings from shifting away from single occupant vehicles (SOVs) may simply be the reduction from eliminating one percent of SOV VMT. This shift could also be achieved through biking, walking, telecommuting, shorter trip lengths, and other measures aimed at reducing demand for travel altogether.

Intercity travel is similarly dominated by personal vehicle travel, which accounts for 90 percent of U.S. person-miles traveled (with air, bus, and train accounting for just 7, 2, and 1 percent). Personal vehicles tend to offer the lowest carbon emissions per person-mile traveled for round-trips under 300 miles, while air dominates for trips of more than 2,000 roundtrip miles (NHTS 2001). In intercity travel as in intracity travel, driving becomes competitive at higher occupancies.

Air travel is presently more efficient than driving solo due to its high average occupancies, though occupancy level, vehicle fuel economy, and trip length cause variations in air travel emissions. Occupancies and aircraft fuel economies are both trending upwards: passenger load factors were up from 62.4 in 1990 to 78.8 in 2006 (Davis and Diegel 2007), and technological advances (including modern high-bypass turbofans and new, lightweight, high-strength materials) have improved energy and aerodynamic efficiency. Improved aircraft fuel economy is limited by turnovers in aircraft (which tend to have 35- to 40-year useful lives) and capacity additions; fuel economy is forecast to improve 16% compared to a 2001 baseline while 70% of aircraft should be post-2002 additions by 2020 (FAA 2005). Air travel GHG emissions also vary with trip length, since take-off and landing are larger energy drains than constant-elevation flying. According to the World Resources Institute (WRI 2006) 0.53 lbs CO2/pax-mi is emitted for a short trip, 0.43 lb/pax-mi for medium trips, and 0.4 lb/pax-mi for long trips[3]. Finally, air travel emissions may be conservatively estimated due to failure to account for indirect emissions from airport access and egress, supportive airport vehicles, and auxiliary power units at airports as well as concerns that emissions at higher altitudes (as 90% of air travel CO_2 emissions are [FAA 2005]) may have a higher GWP.

High speed rail (HSR) is an inter-city mode alternative not currently available in the U.S., but successfully deployed around the world, under study for many U.S. corridors, and actively being pursued in China. Based on per-passenger energy intensities from train technologies existing in

[3] The average short trip is roughly 200 miles, medium trip is 700 miles, and long trip is 1500 miles; the numbers in Table 5 and 6 correspond to 0.63 lbs CO_2e/pax-mi.

other countries (Denmark's IC-3 and France's TGV) or explored by the U.S. Army Corps of Engineers, and assuming HSR is deployed in corridors where it is competitive with flying (e.g. trips of 200-500 mi.) and nets a similar percent occupancy of 0.7, Kockelman et al. (2009) estimate HSR to be very competitive with driving, even with vehicles at high occupancies. The ability to reduce the carbon intensity of HSR via improvements in electricity generation may give it a further edge.

Electric-Bike and Car Sharing

Another, mode-related option for consideration is bike and/or car sharing, where shared vehicles may be available at the worksite and/or home neighborhood for use as needed. Much like a highly accessible form of car rental, such systems provide members with more appropriate vehicle type choices as needed (e.g., a sports utility vehicle for weekend camping trips, a small pickup for moving new furniture, an electric bike for a lunchtime errand, and a small commuter car once or twice a week for work meetings). Such flexibility helps ensure a more efficient fuel-to-passenger ratio and parking space use while encouraging a shift to other modes (see, e.g., Shaheen et al. 2006, Bergmaier et al. 2004).

Car-sharing membership rates, ease of vehicle availability and adequate presence of other, competitive modes are key to energy and emissions reductions. Moreover, travel distance reductions are not always dramatic (and may actually increase, as previously carless households become members). Nevertheless, the fleet-based nature of this approach, with potentially much more balance in choice and need (by vehicle type, time of day, and location needed) suggests that vehicle sharing is a sound option to promote and pursue, even in the form of multiple simple cooperatives, by friends and neighbors (thus reducing administrative overhead). In this way, ownership rates of pickups, SUVs, and other specialized but relatively inefficient vehicles may fall, along with overall vehicle ownership rates and vehicle sizes, allowing a community's average fuel economy and shifts to more efficient modes to rise.

CONCLUSIONS

The sheer magnitude and complexity of actors involved in the problem of GHG emissions undoubtedly means that effective abatement policies will be comprehensive and multifaceted, employing a variety of options to some extent. It is important to know where the biggest GHG reductions can be made in the near and longer terms.

In terms of land use decisions and related policies, the most substantial GHG reductions are likely to emerge from parking supply policies. Residential parking space pricing (in multi-family units, for example) impacts vehicle ownership, and commercial parking policies (including caps, pricing, and cash-outs to employees) impacts mode choices. Certainly, in the near term such policies are easier to adopt than those that involve construction of new buildings and neighborhoods, and renovation of ones. Many downtown U.S. neighborhoods already charge much more than $50 per month for parking, a policy that could reduce transport-related GHG emissions by 16%, due to mode choice shifts (away from SOVs) and reduced vehicle ownership (particularly if applied at the residence). And $90/month may be closer to the true cost of such parking, resulting in further savings. Charging higher rates for curb parking also may reduce trip generation and cruising time, helping relieve downtown congestion while reducing VMT.

As a proxy for a variety of relevant neighborhood attributes (including parking availability and price) population density has consistently proven a strong indicator of travel behaviors, relative to most other attributes of urban form. Of course, pockets of density may bear little fruit; overall, regional densification is most associated with energy conservation, but obviously harder to achieve in existing, developed areas. Attention to the relative positioning of jobs, housing, and other activity locations can be helpful in reducing longer-term GHG emissions, by impacting trip distances, vehicle ownership decisions (both number and type), transit‘s competitiveness, mode choices, and building size.

Alas, urban form in long established regions is slow to change, and estimated impacts appear relatively weak, in terms of transportation effects. Policies requiring more efficient appliances, temperature settings, insulation practices, vegetative shading, and technologies for cooling and heating residential and commercial structures demonstrate meaningful potential for reducing energy demands and CO_2 emissions in the near- to medium-term. Over the longer term, requirements for better building design, particularly high R-value insulation, a shift toward multi-family structures and smaller dwelling units, use and re-use of lower-energy building materials, and more compact urban arrangements will bear more significant and enduring savings. Again, these sort of changes will probably require dramatic changes in building codes and zoning regulations (in cities and in unincoporated areas), particularly in colder climates. Finally, the notion of reducing, reusing, and recycling merits mention here. Simply extending the useful life of various consumer items, along with reduced packaging, can bear multiple benefits (including substantial cost savings). Water-use reductions and recycling of grey water also offer important energy benefits, which often go neglected in the literature (most likely due to data and other information limitations).

While all of these activities applied across the board, without demolishing existing structures and scrapping vehicles before their standard life spans, can take us a long way, the question remains: Can developed nations achieve a 80-percent or even a 50-percent reduction in their energy demands and GHG emissions over the coming decades, as populations and incomes rise, and as consumer preferences and global supply chains expand? It appears that such reductions will require tremendous behavioral shifts, motivated by policies that introduce significant energy taxes, household-level carbon budgets, and cooperative local and international behavior in the interest of the global community. China is very fortunate in that its culture still favors efficiency, and its vehicle and building markets can be tightly managed. With its one-child policy, China helped stem the tide in world over-population; with its land development, building design, and mode preference policies, it may lead the world in sustainable urban form and policy.

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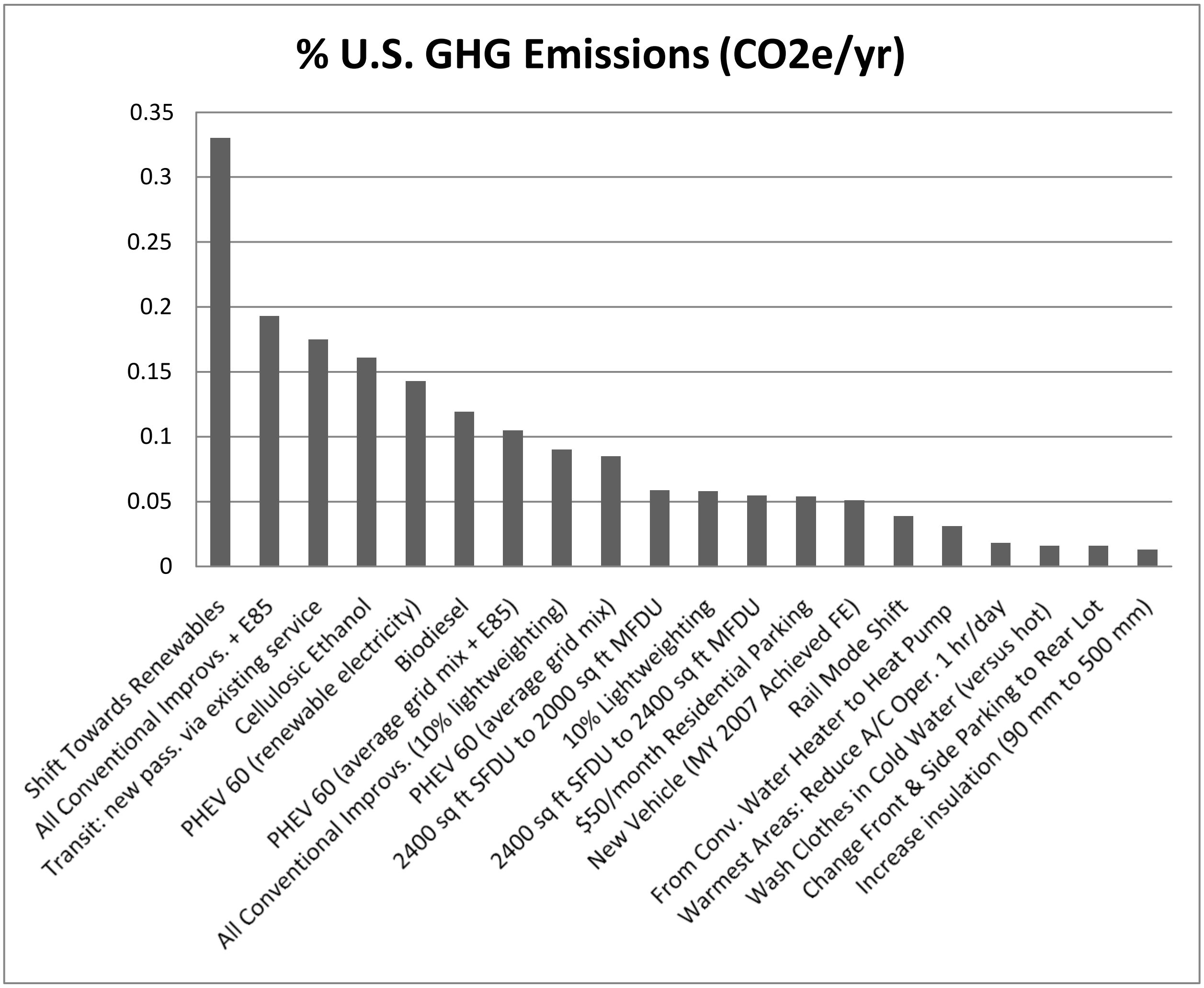

Figure 1. Estimated Percentage Changes in GHG Emissions across Strategies, assuming a 1-Percent Adoption Rate in the United States (Source: Kockelman et al. [2010], Figure 10)