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Impacts of Transportation Policies on Greenhouse Gas Emissions in U.S. Regions

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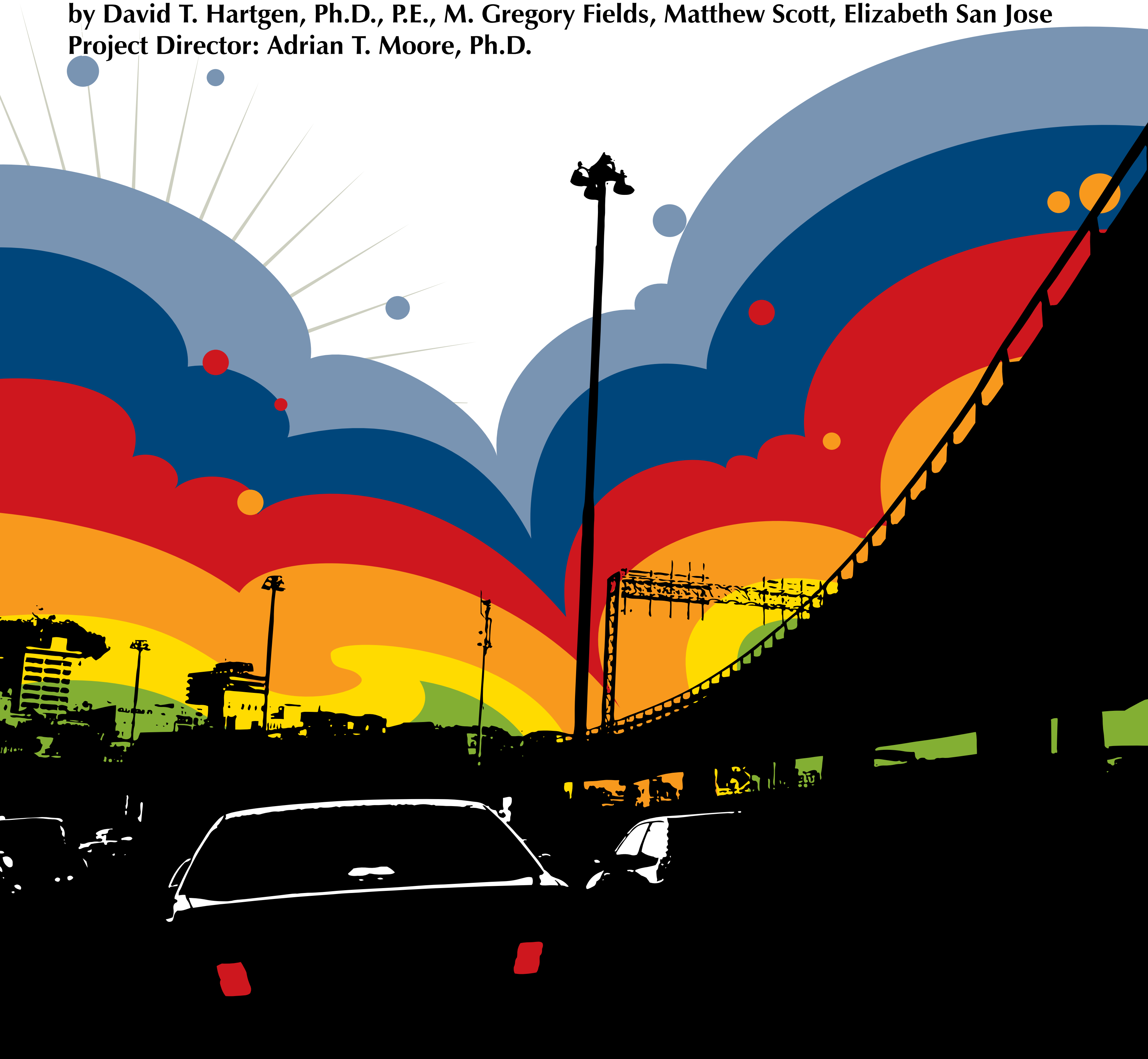
Project Director: Adrian T. Moore, Ph.D.



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Executive Summary

This report compares the cost and effectiveness of improved fuel economy, transportation system improvements and shifts in travel behavior on the reduction of man-made CO_2 emissions in urban areas. We study in detail 48 major U.S. regions containing 41% of the U.S. population, 60% of transit use and 90% of congestion delay. This report quantifies how much CO_2 cars, light trucks and commercial trucks currently emit (base year 2005) in each region, how much CO_2 would have increased with prior CAFE standards, how much the new CAFE standards will reduce, and how much CO_2 might be reduced by other commonly suggested policies. These policies include the new fuel economy standards, additional smaller-car sales, signal timing and speed controls, capacity increases, high-occupancy or priced lanes, travel reduction polices, transit use increases, carpooling, telecommuting and walking to work. We then assess the cost versus effectiveness of each policy for each region and recommend detailed regional strategies.

Interest in man-made CO_2 has sharply increased in the last several decades. A small portion of global CO_2 emissions is a byproduct of fossil fuel combustion from human activity. Most such combustion occurs in the production of energy, and about a third of this involves transportation. CO_2 reduction policy options in the transportation sector primarily focus on the reduction of man-made combustion through the reduction of the underlying activity (i.e., travel), or through reducing the amount of CO_2 in vehicle exhaust by mandating increased vehicle fuel efficiency.

New Corporate Average Fuel Economy (CAFE) standards setting an overall new-car/truck efficiency of 35 MPG by 2020 have recently been put in place. The Supreme Court has ruled that even though CO_2 is not a “listed pollutant,” the EPA must provide standards for its management.

The U.S. transportation community is also increasing attention to the issue. The Transportation Research Board, a national transportation research organization, made “climate change” its theme for its 2009 meeting. At the state and local level, according to a recent survey, 36 states and several hundred local governments have “signed on to aggressive plans to cut back greenhouse gas emissions from electric energy generation, industry, and transportation.” California has recently passed legislation calling for a reduction in greenhouse gas emissions to 1990 levels by 2020.

This interest in emission-reduction goals has materialized without much region-specific research or economic assessment. A few regions have conducted substantial analyses. However, baseline estimates of CO_2 in specific urban regions, and the impact of plans to reduce it, have not yet been developed. Many factors affect transportation’s contribution to greenhouse gas levels in various urban regions, and because each urban area is unique in its transportation needs and behavior and the costs and effectiveness of various emission-reduction policies, a one-size-fits-all plan is not appropriate. In order to balance achievable impact with affordable costs, each region must tailor its policies. Region-specific data would be very helpful to local governments and transportation communities in preparing sensible plans to reduce emissions most cost-efficiently.

This study compares the cost-effectiveness of attempting to reduce CO_2 emissions through specific transportation systems and behavior policies with the likely impact of new federal CAFE standards alone in 48 major U.S. urbanized areas. This study:

- Determines year 2005 CO_2 emissions from car, light truck and commercial truck transportation in each of 48 regions;
- Determines how much CO_2 would be emitted in 2030, with and without the new CAFE standards;
- Determines how much CO_2, relatively and absolutely, might be reduced by 2030 in each region by often-suggested transportation system and behavior policies;
- Determines the cost of these actions and their relative cost-effectiveness, and, based on these findings,
- Suggests strategies for effective actions in different regions.

This approach provides a specific assessment for 48 selected specific regions (see figure below), summarizes the overall impact of selected policies, and yields findings at an ideal time when Congress and the president will be addressing the issue. It promises to be one of the first comprehensive comparative assessments of a range of transportation-related CO_2 policies for specific regions.

Figure ES1: Study Regions

There are no Alaskan or Hawaiian cities in the study.

Alternative fuel source vehicles are not included in this assessment because such research would depend highly on as-yet unquantifiable variables such as gasoline costs, research and development, vehicle features, manufacturing issues, technological breakthroughs, national supply systems, government subsidies and political support. Further, few if any urban area transportation plans quantify or include a change in fuel type as part of their long-range strategies: of the 48 plans we reviewed for this study, *none* commented significantly on the prospects for alternative fuels. Because of this uncertainty, we have elected not to review alternative fuel source vehicles.

We reviewed the literature and plans for regions and identified the following general policies for study:

- **Mandated fuel efficiency improvements**, e.g. new CAFE standards enacted in 2007.
- **Capacity improvements**, primarily freeway and arterial widenings.
- **Speed-change policies** such as signal optimization, speed harmonization policies (where speed limits are lowered *and* made uniform by lane or direction during periods of congestion to keep traffic flowing more smoothly) and speed capping (setting lower speed limits).
- **Vehicle Miles of Travel (VMT) reductions** or changes in VMT growth rates.
- **High-Occupancy-Vehicle (HOV) and High-Occupancy-Toll (HOT) lanes**—one form of congestion pricing.
- **Transit and carpooling** increases in modal shares for work travel.
- **Work-at-home and walk-to-work** strategies.
- **Shifts in vehicle size mix,** i.e., higher portions of small/medium cars.

Although these are not the only policies one might look at, they cover most of those mentioned in transportation plans.

Table ES1 and Figure ES2 summarize our findings regarding the cost and effectiveness of the policies studied. The transportation plans of the 48 regions forecast, on average, about a 40% increase in population and a 52% increase in travel over the next several decades. Some fast-growing regions predict increases of over 100% in traffic, while other slower-growing regions predict less than 20% growth. Under the prior CAFE standards (the baseline forecast in the table), and conservatively assuming there would be no non-CAFE driven increase in fuel economy, CO2 emissions would also have increased about 721,000 tons daily, or about 52% by 2030, resulting in about 3.1% more global man-made CO_2 emissions compared with 2005.

In reality, manufacturers of automobiles would likely develop more efficient engines and lighter vehicles—especially if fuel prices remain high. In any case, in 2007 the U.S. Congress voted to mandate increases in fuel economy through new Corporate Average Fuel Economy (CAFE) standards, which enter into force this year (2011) and require new car and light truck fuel economy to increase to 35 MPG by 2020. These new standards (Policy 2.A in the table) will reduce about 660,000 tons of CO_2 daily, reducing the forecast emissions by about 31.2% (about 1.9% of global man-made CO_2). In fast-growing regions, this effect will slow the growth of, but not reduce, CO_2 emissions below 2005 levels, while slower-growing regions will have actual reductions in CO_2 emissions from 2005 levels from this action alone. At an initial cost of about $52 per ton of CO_2 reduced, this policy is generally cost-effective across all regions. Policies aimed at additional shifting of vehicle sales to smaller, more efficient vehicles but with conventional fuels (Policy 2.B in the table) could decrease an additional 39,000 tons of CO_2 daily, or about 2.7% (0.16% of global CO_2). In many regions, these two actions may be sufficient to hold 2030 CO_2 emissions at near 2005 levels.

Table ES1: Summary of Findings

Strategy	Description	CO_2, K Tons/ Day	Change, K Tons/ Day	% Change	Max % Impact on Global CO_2 (at 6% of GGHG)	Increm. Annual Cost, $B	Cost per Ton Reduced	High Cost/Ton Regions	Low Cost/Ton Regions	Notes
Current	2005	1,391								
1. Baseline Forecast	2030, No change in average vehicle fuel economy	2,112	+ 721*	+51.8 % (-34.2 % to return to 2005)	+ 3.1 %			Phoenix Houston Raleigh Austin	Albany Rochester Milwaukee Providence	Slow growers fare better
VEHICLE TECHNOLOGY										
2.A Fuel Economy Improvements (already in place)	2030, new mandated CAFE standards	1,452	- 660**	-31.2 %	- 1.9 %	$8.540	$51.77	New York, Rochester	Phoenix, Baton Rouge, Bakersfield	Range $45-$55 per ton reduced
2.B Vehicle Size Mix	Fleet is ½ small cars, but conventional fuel	1,413	- 39***	- 2.7 %	- 0.16 %	(Likely to be a savings)				Likely to be uniform across regions
HIGHWAY IMPROVEMENTS										
3.A Signal Timing and Coordination	Improved signal coordination, arterials only.	1,475	- 35 (vs. 1,510)***	- 2.3 %	- 0.14 %	$0.983	$112	Providence Des Moines Salem	Austin Jacksonville Raleigh	Effective policy for most regions

Table ES1: Summary of Findings

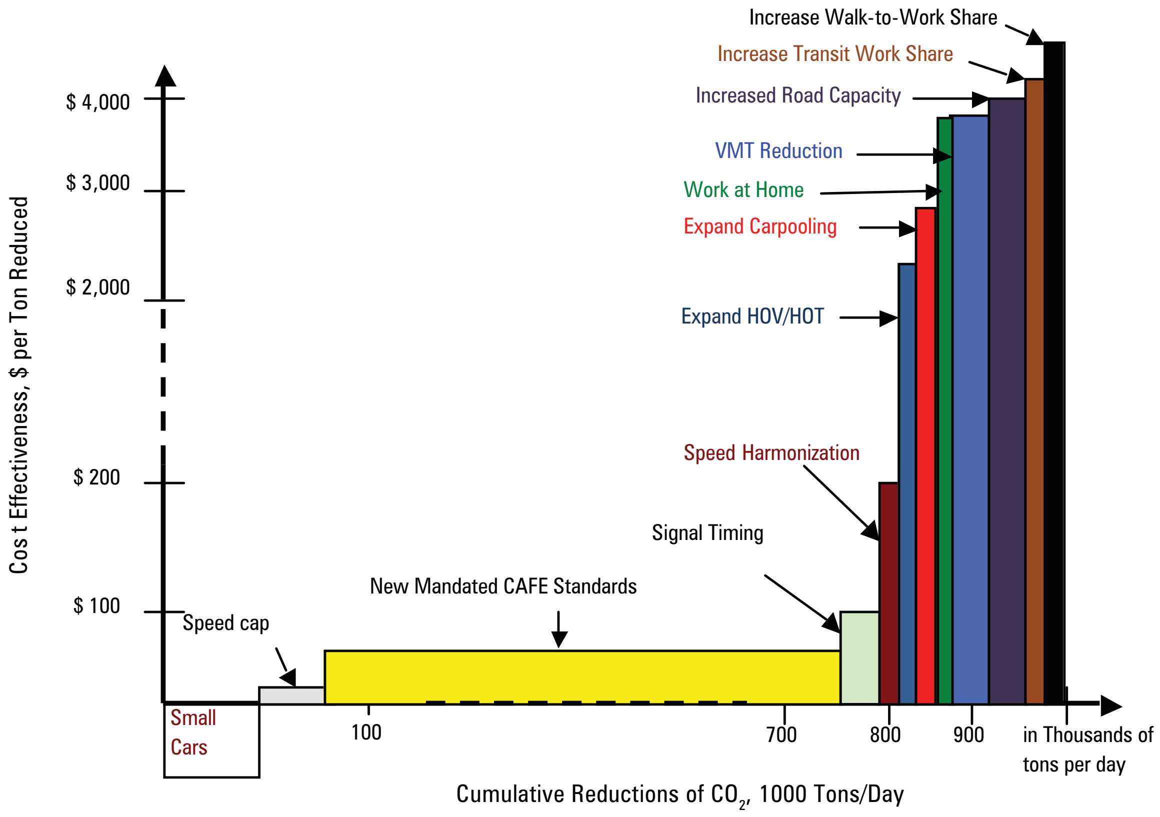
Strategy	Description	CO_2, K Tons/ Day	Change, K Tons/ Day	% Change	Max % Impact on Global CO_2 (at 6% of GGHG)	Increm. Annual Cost, $B	Cost per Ton Reduced	High Cost/Ton Regions	Low Cost/Ton Regions	Notes
3.B Speed Harmonization	Uniform 50 mph, peak hours, freeways	1,493	-17 (vs. 1,510)*	- 1.1 %	-0.07 %	$0.733	$176	Portland OR Dayton Louisville	Austin Providence Orlando	$30-$370 per ton reduced
3.C Capacity Improvements	2030 capacity increases to remove severe congestion	1,447	- 62 (vs. 1,510)***	-4.1 %	- 0.25 %	$62.17	$3,995	Portland OR Raleigh Rochester	Ft Collins Bakersfield Cape Coral	Wide range, $1,019 to $15,200 per ton reduced
3.D Impose Speed Caps (Limits)	55 mph speed limit on freeways, peak and off-peak	1,465	- 45 (vs. 1,510)*	-3.0 %	- 0.18 %	$0.0015	$0.13	Portland OR, Providence, Tulsa	San Fran Los Angeles Phoenix	Large social costs (lost travel time)
TRAVEL BEHAVIOR										
4.A Increase Work at Home (telecommuting)	50% increase in work-at-home share, thru employer incentives	1,444	- 8***	- 0.52 %	- 0.03 %	$6.584	$3,496	Portland OR, Chicago Miami	Bridgeport Madison Jacksonville	Range $503 to $6,700 per ton reduced
4.B Expanded HOV/HOT lanes	Add 10 to 200 lane-miles (double current lane-miles)	1,443	- 9.3***	-0.64 %	- 0.04 %	$5.695	$2,462	Columbia Providence Portland OR	San Fran LA Phoenix	Range $422-$38,000
4.C Expand Carpooling Services	25% higher carpool work share, through agency vanpool services	1,441	- 11***	-0.75 %	- 0.05 %	$7.550	$2,776	Bridgeport New York Salem OR	Bakersfield McAllen Milwaukee	Wide range
4.D Reductions in Travel	5% reduction in 2030 Car/Lt Truck VMT, price increases	1,394	- 58***	-4.0 %	- 0.24 %	$56.75	$3,923	Rochester Albany Milwaukee	Austin Raleigh Houston	Small range, $3,880- $ 3,957
4.E Expand Transit Services	50% higher transit work share, through expanded service	1,436	- 16***	- 1.1 %	- 0.07 %	$16.60	$4,257	Portland OR Spokane Ogden	Bridgeport San Fran San Diego	$ Wide range, $472-$12,000
4.F Increase Walk to Work	50% increase in walk-to-work share	1,447	- 5***	- 0.35%	-0.02 %	unknown	unknown	unknown	unknown	Implementation cost is likely to be very high

Notes: *Vs 2005 Base **Vs 2030 Null ***Vs 2030 New CAFE
Calculated from 2005 for Policy 1, and from 2030 downward for others.

Other transportation system policies vary considerably in both effectiveness and cost. Improved signal timing and coordination (Policy 3.A in the table) has the potential to reduce about 35,000 tons of CO_2 daily (about 2.3% of regional CO_2 emissions), but at $983 million annually it costs about $112 per ton reduced. By region, its cost-effectiveness varies from about $30 per ton reduced to about $370, though it has the additional advantage of reducing driving time costs. Speed controls for freeway systems are relatively inexpensive, but have large societal costs in increased travel time. A 55 mph speed limit in urbanized areas (Policy 3.D in the table) would reduce about 45,000 tons of CO_2 daily (about 3.0% of regional CO_2 emissions) and cost just $1.5 million annually or $0.13 per ton reduced. But it would also cost drivers about $12 billion annually in increased time spent traveling, and enforcement costs might be considerable. Peak-hour speed harmonization on freeways (Policy 3.B in the table) would decrease about 17,000 tons of CO_2 daily, about 1.1% of CO_2 emissions, and at $733 million its cost-effectiveness is about $176 per ton reduced, but this policy would also impose significant costs in lost time (on the order of $730/ton). Road capacity improvements (Policy 3.C in the table) could reduce up to about 62,000 tons of CO_2 daily (about

4.1% of CO_2 emissions) but are much more expensive at $62.2 billion annually, and hence even less cost-effective, at $3,995 per ton decreased. They also vary widely by region and functional class, and therefore should be targeted to only the most cost-effective specific projects within each region.

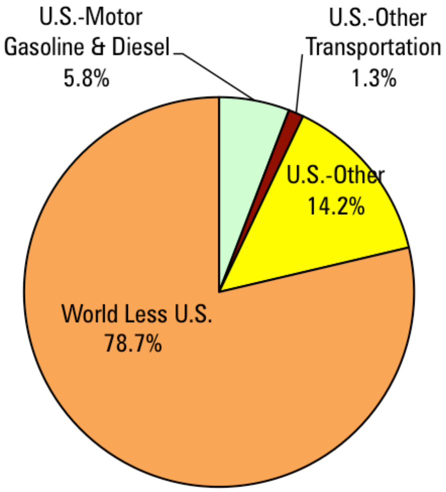
Figure ES2: Summary of Cost-Effectiveness and CO_2 Reduction



Policies aimed at changing travel behavior have mixed impact and vary widely in cost-effectiveness. Increasing work-at-home shares by 50% could reduce about 8,000 tons of CO_2 daily (about 0.52% of regional CO_2 emissions) and at $6.6 billion annually would cost $3,496 per ton reduced. Increasing walk-to-work shares by 50% would reduce about 5,000 tons of CO_2 daily (about 0.35% of CO_2 emissions), however, its cost, not estimated, is likely to be extremely high. Doubling HOV and HOT lanes on urban freeways could reduce about 9,000 tons of CO_2 daily (about 0.64% of regional CO_2 emissions), but would require lane construction and at $5.695 billion annually, costs about $2,462 per ton reduced (though there are other benefits to such lanes than CO_2 emission reductions, such as improved traffic flow, reduced congestion and more travel options for drivers). It is also most applicable in the largest regions that have significant congestion. Expanding vanpooling services to increase carpooling shares by 25% would reduce about 11,000 tons of CO_2 daily (about 0.75% decrease in CO_2 emissions), but if operated at current rates would cost $7.6 billion annually, which is about $2,776 per ton reduced. An across-the-board 5% reduction in personal travel would reduce about 58,000 tons of CO_2 daily, about 4.0% reduction in CO_2 emissions. However, gasoline prices would have to average close to $5/gallon to achieve such a reduction, and this cost, about $56.8 billion annually, is about $3,923 per ton reduced. Increasing transit shares by 50% would reduce about 16,000 tons of CO_2 daily, but the service increase needed to achieve this would cost about $16.6 billion annually, or about $4,257 per ton reduced. However, no single policy would reduce more than 0.25% of global CO_2 emissions.

This study concludes that technological improvements to vehicles that result in higher fuel economy, along with traffic signal harmonization, speed harmonization and additional shifts to smaller vehicles, hold out the most hope for significant reductions in surface transportation CO_2 emissions, if that remains a policy goal. Speed limits are not recommended because of their large societal costs. These policies can generally reduce modest amounts of CO_2 emissions at a cost of around $180/ton reduced. Other policies such as expanded HOV-HOT lanes, carpooling, capacity improvements, VMT reductions and transit service improvements are likely to be considerably less cost-effective, although of course there are other reasons for doing them. , Moreover even large "baskets" of policies are not likely to reduce U.S. transportation CO_2 emissions more than about 10-15% below 2005 levels in most regions, or global CO_2 emissions by more than 0.5%. Given the wide range of circumstances across regions, we recommend detailed, project-by-project assessments in each region.

Figure ES3: Global Man-Made CO_2 Emissions, 2006



Source: Data from the *Transportation Energy Data Book 27*, Tables 11-1, 11-5 and 11-6.

Total emissions from all vehicles in the United States comprise 5.8% of global man-made CO_2 emissions, with this share decreasing over time as emissions from other countries, especially India and China, increase theirs. Indeed China has now surpassed the U.S. in gross CO_2 emissions. Over the next 50 years, the U.S. gasoline and diesel share of global man-made emissions is likely to fall substantially. Therefore, a 10% reduction of surface U.S. transportation emissions would result in at most 0.6% reduction in global emissions totals. The small size of this impact must be considered when comparing alternatives and developing strategies.

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Part 1

Introduction

A. Issues

Climate change is considered by many to be a key issue facing the nation. It is often discussed in the context of greenhouse gases, thought to increase temperatures and possibly humidity. There are several types of greenhouse gases, the most common of which are water vapor and carbon dioxide (CO_2). CO_2 is produced primarily by the decomposition of vegetable matter and animate respiration, and forms part of the Earth's carbon cycle. However, a small portion of CO_2 is a byproduct of fossil fuel combustion from human activity. Most such combustion occurs in the production of energy, and about a third of this involves transportation. CO_2 reduction policy options in the transportation sector primarily focus on the reduction of man-made combustion through the reduction of the underlying activity (i.e., travel), or on the control of emissions. Examples of these policy options include reducing vehicle-miles of travel (VMT[1]) and reducing the amount of CO_2 in vehicle exhaust through increased vehicle fuel efficiency.

The interest in man-made CO_2 has sharply increased in the last several decades. The Supreme Court has ruled that even though CO_2 is not a "listed pollutant," the EPA must provide standards for its management.[2] In 2009, the president directed the EPA to reconsider California's request for higher emissions standards and to move forward with faster implementation (by 2011) of the new Corporate Average Fuel Economy (CAFE)[3] standards adopted in 2008 (rules approved April 2010), and to fast-forward the review of CO_2 as a possible "listed pollutant."[4]

The U.S. transportation community is also increasing attention to the issue. The Transportation Research Board, a national transportation research organization, made "climate change" its theme for its 2009 meeting.[5] At the state and local level, according to a recent survey, 36 states and several hundred local governments "signed on to aggressive plans to cut back greenhouse gas emissions from electric energy generation, industry, and transportation."[6] Also in 2009, California passed legislation calling for a reduction in greenhouse gas emissions to 1990 levels by 2020.[7] Congress is considering legislation to reduce per-unit transportation emissions 5% below 2005 levels by 2023 and 10% by 2030. However, Governor Christie took New Jersey out of the Regional Greenhouse Gas Initiative, signaling perhaps a wider change in direction away from such aggressive state and local policies.

This interest in emission reduction has materialized without much region-specific research or economic assessment.[8] A few regions, however, have conducted substantial analyses. One study is the transportation-related greenhouse gas assessment for the Los Angeles region.[9] This assessment found that greenhouse gases from regional VMT would grow by about 38% (from 72,670 to 100,000 tons daily from 2004 to 2030), but that the projects in the long-range transportation plan would reduce these emissions by just 0.75%, about 750 metric tons daily.[10] However, this assessment pre-dates the new CAFE standards.

Baseline estimates of CO_2 in specific urban regions, and the impact of plans to reduce it, have not yet been developed. Several national studies, notably the "Moving Cooler" initiative,[11] have prepared estimates of impact for the United States. Such information would be very helpful to regions in preparing sensible plans that balance achievable impact with affordable costs.

The goal of this study is to determine the cost-effectiveness (impact and costs) of specific transportation systems and behavior policies on the reduction of CO_2 emissions in the transportation sectors of 48 major U.S. urbanized areas, compared with impact likely to occur from the new CAFE standards alone. The specific objectives of the study are to:

- Determine how much CO_2 was emitted in the baseline year (2005) by car, light truck and commercial truck transportation in each of 48 regions;
- Determine how much CO_2 would be emitted in 2030, with and without the new CAFE standards;
- Determine how much CO_2, relatively and absolutely, might be reduced by 2030 in each region by often-suggested transportation system and behavior policies;
- Determine the cost of these actions and their relative cost-effectiveness and, based on these findings,
- Suggest strategies for effective actions in different regions.

This approach provides a specific assessment for 48 selected specific regions, summarizes the overall impact of selected policies, and yields findings at an ideal time when Congress and the president are addressing the issue. It promises to be one of the first comprehensive comparative assessments of a range of transportation-related CO_2 policies for specific regions.

B. Method

The analysis focuses exclusively on CO_2 emissions from cars, light trucks and commercial trucks. Beginning with reviews of the transportation planning documents for the 48 regions, we assess various regional and state CO_2-reduction activities and initiatives, estimate present and future CO_2 for each region, and determine the approximate costs and expected results from these policies. Because of wide variation in costs of construction or costs of changing travel behavior, these costs are likely to be more uncertain than are the estimated emission reductions.

The basic approach taken in this study is that the impacts of policies to reduce CO_2 emissions can be estimated by determining the extent to which each policy affects various components of travel.

For a given region, travel-related CO_2 emissions can be thought of as the product of three terms:

$$CO_2 = (\text{VMT}) \times (\text{gallons/vehicle-mile}) \times (CO_2\ \text{emissions/gallon equivalent})$$

The first term (VMT) represents the total regional travel, by component. It depends on average household travel, transit use, carpooling and other factors that determine total regional travel, and on commercial truck travel. The second term, "gallons per mile" (the inverse of fuel efficiency's MPG), is primarily a function of vehicle age, vehicle type and operating speed. This term depends on fuel efficiency, federal CAFE standards, the proportion of new versus older vehicles, and on-the-road traffic operations. The third term is the "fuel intensity" (the CO_2 emissions per gallon of fuel equivalent), which is generally constant for a given fuel type but varies considerably for different fuel types. Its average value for a region depends on the proportion of vehicles of different fuel types or efficiencies in the regional vehicle population.

For implementation this model must be further partitioned by vehicle type and mode. U.S. urbanized areas vary widely in the amount of traffic on the various classes of roads (which affects speeds and truck percentages), transit and carpool use; they vary less so (but somewhat) on vehicle sizes and fuel-type mixes. Therefore, to provide the necessary detail to test alternative policies for a given region, data must be available on future regional traffic by road type (functional class), peak and off-peak speeds, vehicle efficiency, fuel and size mix, and mode. Data on variations in emissions rates and fuel consumption are less variable and are readily available in the literature.

Alternative fuel source vehicles are not included in this assessment. Although many studies focus on the characteristics and costs of alternative fuel vehicles, the basic information (added cost per vehicle, fuel efficiency and sales) is highly dependent on key assumptions about gasoline costs, research and development, vehicle features, manufacturing issues, technological breakthroughs, national supply systems, government subsidies and political support. At this point, with the possible exception of plug-in hybrid gasoline-electric vehicles, there is no clear "breakout" technology on the horizon. Further, few if any urban area transportation plans quantify or include a change in fuel type as part of their strategies: of the 48 plans we reviewed for this study, *none* commented significantly on the prospects for alternative fuels. Because of this uncertainty, we have elected not to extensively review alternative fuel source vehicles. We *do* look at one vehicle technology policy—vehicle size distribution—but we assume conventional fuels. Therefore, the primary focus of this study is the effect of policies that focus on conventional vehicle technology (the new CAFE standards, shifts to smaller cars), highway system improvements (capacity actions, signals, speeds, etc.) and travel behavior (transit service, carpooling, telecommuting, VMT reduction and congestion pricing). We cover both peak-hour and all-day transportation policies.

A study of this nature requires data from a wide range of sources and a practical methodology. Major data sources include the federal government's Highway Performance Monitoring System (HPMS) Urbanized Area tables,[12] long-range transportation plans (LRPs) from the studied regions, the traffic assignment and modal split models developed for each region to forecast travel, air quality conformity results for each region, freeway traffic monitoring systems in various regions, congestion management systems and Census data. While all of these are useful, we chose the HPMS database as the starting point for the analysis. This national database is generally consistent across urbanized areas, has been largely in place for several decades and contains, through special tabs, additional information on commercial truck statistics. It also forms the basis for other indicators such as congestion indices. We supplement these data with detailed information from the long-range transportation plans of the 48 regions, the U.S. Census, freeway monitoring systems and air quality plans.

The specific steps in the research are:

1. **Select regions**. We selected a total of 48 regions for this assessment (Figure 1). These include all regions over three million persons, most regions between one million and three million (a few, notably Boston, Salt Lake City, Cleveland, Kansas City, San Antonio, Baltimore, Memphis and Nashville are not included because of time and budget constraints) and selected smaller regions ranging in size from one million persons to 200,000 persons. Selection of regions was limited to those studied in detail in two other studies,[13] in which the transportation plans of these regions had already been collected and reviewed. We cannot do national "roll-ups" of CO_2 estimates from just these 48 regions, but they do include most large regions and a cross-section of smaller regions, including 18 regions in the 100,000–500,000 population range. Other regions can also be analyzed; readers interested in expanding our study to other regions or to other policies are invited to contact the authors.

2. **Gather background data**. For each of 48 regions, we extracted and organized data on travel and road mileage by functional class for 1995 and 2005, along with speeds by functional class and other statistics such as population, employment, congestion (TTI[14]), transit use, carpooling, walking and work-at-home shares. We used urbanized area statistics from the Census and the modeled region from the regional long-range plans, somewhat smaller than metropolitan statistical area (MSA) data, for comparability. Travel was partitioned by peak/off peak and vehicle type (cars and light trucks, single-unit commercial trucks and combination trucks). We then forecast travel by functional class/vehicle type/time of day to 2030, using each region's long-range plan forecasts of VMT and shift-share allocations. Table 1 summarizes some of this information. In total, these regions account for about 41% of the U.S. population, but 60% of transit use and 90% of congestion delay. Depending on the policy, estimates for the U.S. as a whole can be scaled proportionally.

Figure 1: Study Regions

There are no Alaskan or Hawaiian cities in the study.

Table 1: Selected Statistics, 48 Urbanized Areas

Region ***(In order by Base Year Pop)***	**2004-7 Pop, M (LRP)**	**Public Transit Mode to Work Share, 2005**	**2030 Pop, M (LRP)***	**2005 Daily VMT, M (HPMS)**	**2030 Daily VMT, M (LRP)**	**TTI Congestion Index, 2030**
New York-Newark	18.9	30.6	22.1	283	389	1.69
Los Angeles-Long Beach	16.6	5.8	22.9	322	482	1.86
Chicago	8.1	11.9	10.1	146	177	2.05
Miami	**6.7	3.6	9.4	104	160	1.84
San Francisco-Oakland	6.3	15.9	8.8	144	201	1.86
Dallas-Fort Worth	5.9	1.9	8.5	151	241	1.73
Philadelphia	5.3	9.7	6.0	103	130	1.61
Washington	5.0	15.7	6.1	126	166	1.87
Houston	4.7	3.2	8.8	125	266	1.58
Atlanta	3.7	4.0	6.0	135	192	1.92
Phoenix-Mesa	3.5	2.5	6.1	86	193	1.64
Seattle-Tacoma	3.3	7.6	4.5	66	95	1.79
San Diego	2.8	3.1	3.8	70	108	1.86
Denver-Aurora	2.7	4.3	3.9	58	104	1.80
Minneapolis-St. Paul	2.6	4.8	3.1	57	86	1.76
St. Louis	2.5	2.8	2.8	63	80	1.42
Sacramento	2.1	2.4	3.1	55	85	1.73
Milwaukee	2.0	3.5	2.3	40	47	1.35
Portland, OR	1.6	7.6	2.4	20	28	1.75
Orlando	1.4	2.0	2.2	42	71	1.59
Austin	1.2	3.8	2.8	31	73	1.54
Providence-Fall River	1.0	2.9	1.1	21	25	1.36
Tampa	***1.0	1.4	1.5	64	99	1.50
Louisville	0.9	2.3	1.1	31	47	1.44

Table 1: Selected Statistics, 48 Urbanized Areas

Region *(In order by Base Year Pop)*	**2004-7 Pop, M (LRP)**	**Public Transit Mode to Work Share, 2005**	**2030 Pop, M (LRP)***	**2005 Daily VMT, M (HPMS)**	**2030 Daily VMT, M (LRP)**	**TTI Congestion Index, 2030**
Richmond-Petersburg	0.8	2.1	1.1	24	36	1.17
Dayton	0.8	1.8	0.8	19	24	1.16
Raleigh	0.7	1.0	1.4	20	45	1.37
Bakersfield	0.7	2.2	1.2	21	38	1.14
Albuquerque	0.7	1.5	0.9	14	26	1.36
Rochester, NY	0.7	2.0	0.7	22	26	1.14
Jacksonville	0.6	1.4	1.1	32	54	1.36
McAllen	0.6	0.2	1.0	9	15	1.11
Baton Rouge	0.6	1.5	0.8	13	19	1.12
Knoxville	0.6	0.7	0.9	28	40	1.12
Boise	0.5	0.6	1.0	11	20	1.11
Tulsa	0.5	0.8	0.8	21	28	1.21
Grand Rapids	0.5	1.1	0.9	20	28	1.28
Cape Coral	0.5	0.9	0.9	14	27	1.36
Albany-Schenectady-Troy	0.5	2.9	0.6	23	26	1.15
Fort Collins	0.5	1.0	0.9	11	18	1.11
Columbia, SC	0.5	1.8	0.6	10	14	1.09
Ogden-Layton	0.5	2.1	0.7	11	17	1.12
Lancaster, PA	0.5	1.5	0.6	8	10	1.11
Des Moines	0.5	1.0	0.7	10	17	1.11
Spokane	0.4	2.5	0.6	10	15	1.15
Madison	0.4	4.9	0.3	13	18	1.11
Bridgeport-Stamford	0.3	9.3	0.3	21	26	1.62
Salem, OR	0.2	2.5	0.3	4	6	1.23
Total/Average	123.0	4.2	169.0	2,731	4,139	

*As reported in LRP for a larger planning area. May be optimistic. **Includes Broward and Palm Coast. ***Excludes St. Petersburg.

3. Identify policies for reducing CO_2 emissions. We reviewed the literature and plans for regions and identified the following general policies for study:

- **Mandated fuel efficiency improvements**, e.g. new CAFE standards enacted in 2007.
- **Capacity improvements**, primarily freeway and arterial widenings.
- **Speed-change policies** such as signal optimization, speed harmonization policies (where speed limits are lowered *and* made uniform by lane or direction during periods of congestion to keep traffic flowing more smoothly) and speed capping (setting lower speed limits).
- **VMT reductions** or changes in VMT growth rates.
- **High-Occupancy-Vehicle (HOV[15]) and High-Occupancy-Toll (HOT) lanes**—one form of congestion pricing.
- **Transit and carpooling** increases in modal shares for work travel.
- **Work-at-home and walk-to-work** strategies.

- **Shifts in vehicle size mix,** i.e., higher portions of small/medium cars.

We include major technology actions, commuting policies and more general all-day policies, such as VMT reductions, capacity improvements and speed controls. Although these are not the only policies one might look at, they cover most of those mentioned in transportation plans.

4. Analyze data. We first estimated the transportation-related CO_2 emissions for each region for the baseline (prior CAFE standards) and the forecast (new CAFE standards) for 2005 and 2030. Our choice of the base year, 2005, is necessitated because no comparative data for earlier years such as 1990 are available, and in any case the regions have changed so much since 1990 that comparison with that year would not be meaningful. These years were chosen for consistency, since most long-range transportation plans are for 2030. We then analyzed the impact of each policy on CO_2 reduction, compared with the baseline forecast, for each region.[16] This step varies somewhat by policy, depending on the nature of the impact and its effect on traffic and emissions. The basic procedure was to simulate the policy's impact at a given reasonable level of penetration/adoption, by calculating how a given policy would affect CO_2 emissions. All estimates of CO_2 emissions are in tons per day. This is necessary because virtually all regional and Federal Highway Administration (FHWA) VMT data are in average weekday VMT, not annual VMT. We report findings in reduction of CO_2 in tons per day, and in percent reduction from the baseline forecast, i.e., the CO_2 emissions that would be produced in 2030 under the prior CAFE standards. We also estimated the overall global impact of each policy.

Then we estimated the direct government and manufacturing cost of each policy by region using best estimates from the literature. These are for the *initial implementation* of each policy (for instance, additional manufacturing costs for increased fuel efficiency, government costs of more transit service, costs of higher gasoline prices needed to reduce VMT, etc.) They do *not* include second-order costs, such as resource extraction, lifecycle or social costs such as lost time, or so-called "co-benefits" such as reduced accidents or operating costs. These steps might be included in selecting specific actions within each region, but are beyond the scope of this study.

Finally we estimated the approximate cost-effectiveness (approximate cost per ton of CO_2 emissions reduced) for each policy for each region.

C. Brief Literature Review

Climate change is a significant topic of research and much work is being done on all of its dimensions. There are several key documents and reports of particular interest to potential solutions in the transportation sector.

McKinsey & Company recently evaluated over 250 options for reducing U.S. greenhouse gas (GHG) emissions over the next 25 years.[17] They found that the United States could reduce these emissions in 2030 by 3.0 to 4.5 billion metric tons of CO_2 equivalent (annually) using a wide range of "tested approaches and high potential emerging technologies," most being available at marginal costs of less than $50 per ton reduced. While most options are for improvements outside the transportation sector, the study does include fuel economy packages for cars and light trucks, reducing the carbon intensities of fuels, and a fuel-hybrid option. Together, these options could reduce 340–660 million metric tons annually, or 11 to 15% of the total potential decrease, which suggests that there is a greater potential to reduce GHG outside the transportation sector than inside. A common thread throughout the study's findings is the need to improve energy production efficiencies in all sectors, with improvements of vehicle efficiencies offsetting the growth in vehicle miles of travel (VMT), while still providing net economic gains.

A 2008 National Academy of Sciences study evaluates various options in several sectors.[18] It describes three time horizons for viewing transportation sector options for reducing GHG emissions. The greatest near-term gains will likely come from relatively conventional vehicle design shifts, with medium-term gains most likely through fuel economy improvements and a shift to plug-in hybrid vehicles. In the long-term, a shift to less carbon-intensive fuels seems most promising.

Our 2007–2008 review of the long-range transportation plans of 48 regions, ranging in size from New York to Salem, Oregon, indicates that most regions (three-quarters of the total) had not yet focused on this issue in their last plan; only two (Los Angeles and Rochester, New York) had included carbon emissions reductions as a measurable outcome of their plans.[19] The Los Angeles plan forecasts that CO_2 emissions will increase about 30% by 2030, but that the actions in the plan would decrease that by less than 1%, from about 98,000 MT daily to about 97,250 MT daily.[20] The Rochester, New York plan makes a preliminary forecast of CO_2 emissions, but does not propose any actions.[21] More recent reviews have found more activity but also little analysis. For example, a 2009 study reviews the stages of transportation planning that might be amenable to climate change analysis.[22] Other research reviewed the activities of 12 states and four MPOs (Metropolitan Planning Organizations), finding that few were quantifying emissions or developing performance measures.[23] Of 18 MPOs contacted, four (Portland OR, San Francisco, Los Angeles and Seattle) had developed performance measures, but only one state (New York) required quantification in local plans. San Francisco estimated 2035 emissions under four scenarios and found that only one (freeway construction) would reduce emissions by more than 10% (the others, HOT-lane pricing and transit-rail, produced less than a 2% reduction). But most MPOs seem to be waiting for guidance from the federal/state governments, and many are clearly preparing to include carbon reductions in their next long-range transportation plan update. In 2008, the Federal Highway Administration issued a report providing guidance for integrating climate change into the transportation planning process.[24] While this report does offer valuable procedural guidance and provide examples of what is currently being done in states and municipalities, it does not recommend regional-specific strategies for dealing with climate change, nor does it provide comparative data for different strategies.

The wait for guidance seems to be nearing an end. State and local governments are beginning to step in to fill what they see as an unfilled federal role. The U.S. Conference of Mayors Climate Protection Agreement, an initiative in which mayors across the United States commit to reducing emissions in their cities to 7% below 1990 levels by 2012 (the Kyoto emissions targets for the United States), now has 902 mayor signers, representing over 81 million U.S. citizens. In the last two years, California has committed (by executive order in 2005, signed into law in 2006) to reducing emissions levels to 2000 levels by 2010, to 1990 levels by 2020, and to 80% below 1990 levels by 2050. With annual emissions levels estimated at 426 million metric tons (MMT) in 1990, 473 MMT in 2000, 532 MMT in 2010, and 600 MMT in 2020, reductions targets are 59 MMT by 2010, 174 MMT by 2020, and 260 MMT by 2050.[25]

In a 2008 survey in *The Urban Transportation Monitor* several transportation officials identified a number of specific goals for CO_2 reduction:[26]

- The New York City Climate Protection Act requires emissions to be reduced 30% by 2030.
- In the San Francisco region, CO_2 emissions must be reduced by 40% below 1990 levels by 2035.
- Washington State has a statewide goal of reducing VMT by 50%.
- Madison, Wisconsin plans to reduce greenhouse gas emissions first to 1990 levels with further reductions thereafter.

In the survey, a number of strategies to reduce CO_2 emissions were rated on a 1 to 10 scale for cost-effectiveness. The top 12 are included in Table 2. Interestingly, eight of the 12 involve VMT reduction and three (3, 11 and 12) focus on improving traffic flow (which typically improves fuel efficiency); only one (2) addresses both fuel efficiency and fuel intensity. Clearly, the survey respondents in the transportation community seem to be focusing on VMT reduction strategies more than fuel efficiency-increasing or fuel intensity-reducing approaches, a finding echoed by some researchers. This is not surprising given the content of the plans for most regions, which generally do not analyze the impact of national strategies such as improved fuel efficiency.

Table 2: Presumed* Cost Effectiveness of Transportation Emissions Reduction Strategies

	Traffic/Transportation Emissions Reduction Strategy	**Average Rating out of 10**
1.	Improved land use planning (transit-oriented development, mixed-use development, etc.)	7.3
2.	Technological improvements to vehicles (hybrid vehicles, electric vehicles, etc.)	7.0
3.	Improve traffic signal timing and synchronization.	6.9
4.	Increase telecommuting by subsidizing implementation.	6.8
5.	Increase transit use by improving/expanding transit.	6.7
6.	Increase transit use by subsidizing transit fares.	6.3
7.	Apply road pricing.	6.3
8.	Apply parking restrictions (local ordinances to specify a maximum rate of parking to be provided for new development rather than a minimum parking rate).	6.0
9.	Increase walking and bicycling by improving facilities.	5.9
10.	Increase ridesharing by subsidizing implementation.	5.9
11.	Increase the application of roundabouts (in place of traffic signals).	5.8
12.	Increase the application of advanced traffic management on highways (ramp metering, use of shoulders as a traffic lane during peak periods, etc.).	5.6

*This table reflects only the views of transportation officials rather than actual data from comparative assessments.

Source: Daniel B. Rathbone, "Transportation Emissions Reductions Strategies," *The Urban Transportation Monitor*, Vol. 22, No. 10, 2008, pp. 12-16.

However, the total emissions from all vehicles in the United States are but a small piece of the global picture. U.S. gasoline and diesel-powered vehicles comprise 5.8% of global man-made CO_2 emissions, with this share decreasing as emissions from India, China and other emerging economies increase.[27] Over the next 50 years, the U.S. gasoline and diesel share of global man-made emissions is likely to fall substantially, as the new CAFE standards come in while other nations grow in traffic. Therefore, a 10% reduction of surface U.S. transportation emissions would result in a 0.6% reduction in global emissions totals. The small size of this impact must be considered when comparing alternatives and developing strategies.

Part 2

Findings

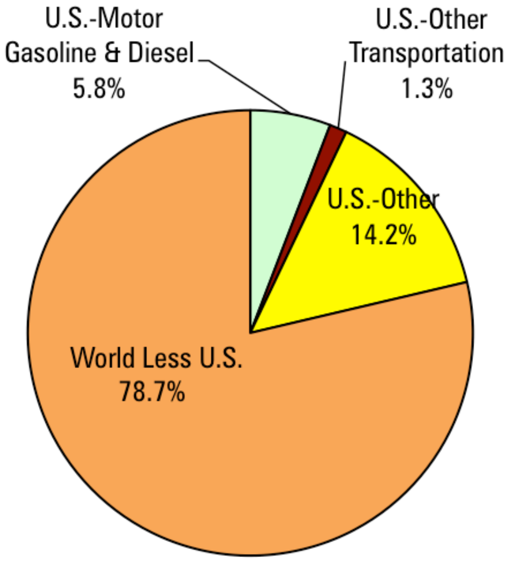
A. Global CO_2 Emissions

Carbon flows are dominated by natural processes, such as plant photosynthesis, respiration, organic matter decay and inorganic matter weathering. Of the total carbon flows, estimated at some 426.9 billion metric tons (MT) annually, worldwide fossil fuel combustion and industrial processes comprise just 6.1 billion MT of carbon (1.5% of the total).[28]

Carbon produced by the man-made combustion processes combines with oxygen and is released as CO_2. In 2006, as shown in the following figure and table, total worldwide CO_2 man-made emissions were about 28 billion metric tons annually, with the United States responsible for about 21% of this total.[29] Of the U.S. man-made CO_2 emissions:

- 33.8% (7.1% of the global man-made total) was transportation-sector related.
- 20.1% (4.2% of the global man-made total) was from gasoline emissions.
- 7.7% (1.6% of the global man-made total) was from diesel emissions.

Figure 2: Global Man-Made CO_2 Emissions, 2006



Source: Data from the *Transportation Energy Data Book 27*, Tables 11-1, 11-5 and 11-6.

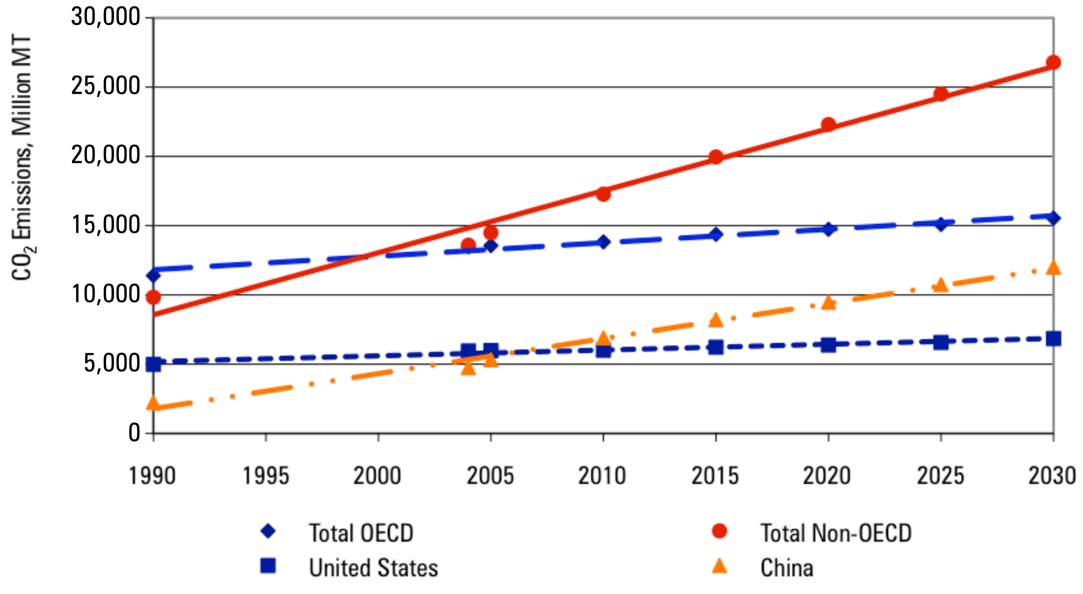
Table 3: CO_2 Man-Made Emissions, Worldwide and in the U.S., Annual 2006

	Metric Tons, M	% of Global	% of U.S.	% of Sector
Global Man-Made Emissions*	28,051	100.0 %		
Non-U.S. Emissions*	22,069	78.7%		
Non-Energy Consumption* Percent		91.7%		
U.S. Emissions, Energy Consumption	5,890	21.0%		
Residential	1,204	4.3%	20.4%	
Commercial	1,045	3.7%	17.7%	
Industrial	1,651	5.9%	28.0%	
Transportation	1,990	7.1%	33.8%	
Motor Gas	1,186	4.2%	20.1%	59.6%
Distillate Fuel (Diesel)	452	1.6%	7.7%	22.7%
Jet Fuel	239	0.9%	4.1%	12.0%
Other	112	0.4%	1.9%	5.6%

* 2005 Data
Source: *Transportation Energy Data Book 27.*

Of all global man-made CO_2 emissions, those resulting from the combustion of motor gasoline and diesel in the U.S. account for just 5.8% of the total. This portion is falling as the economies of developing countries (e.g., China and India) expand. According to Energy Information Administration (EIA) estimates (Figure 3), China surpassed the U.S. as the leading producer of CO_2 emissions in the 2007-08 timeframe and is on track to produce 28% of global man-made emissions by 2030 (vs. 16% for the U.S.).[30] Consequently, any programs implemented in the U.S. to curb global warming by reducing CO_2 emissions from automobiles and trucks would have a decreasing impact on the whole global picture. This limited effect must be weighed against the programs' costs.

Figure 3: CO_2 Emissions for Developed and Developing Countries, 1990-2030

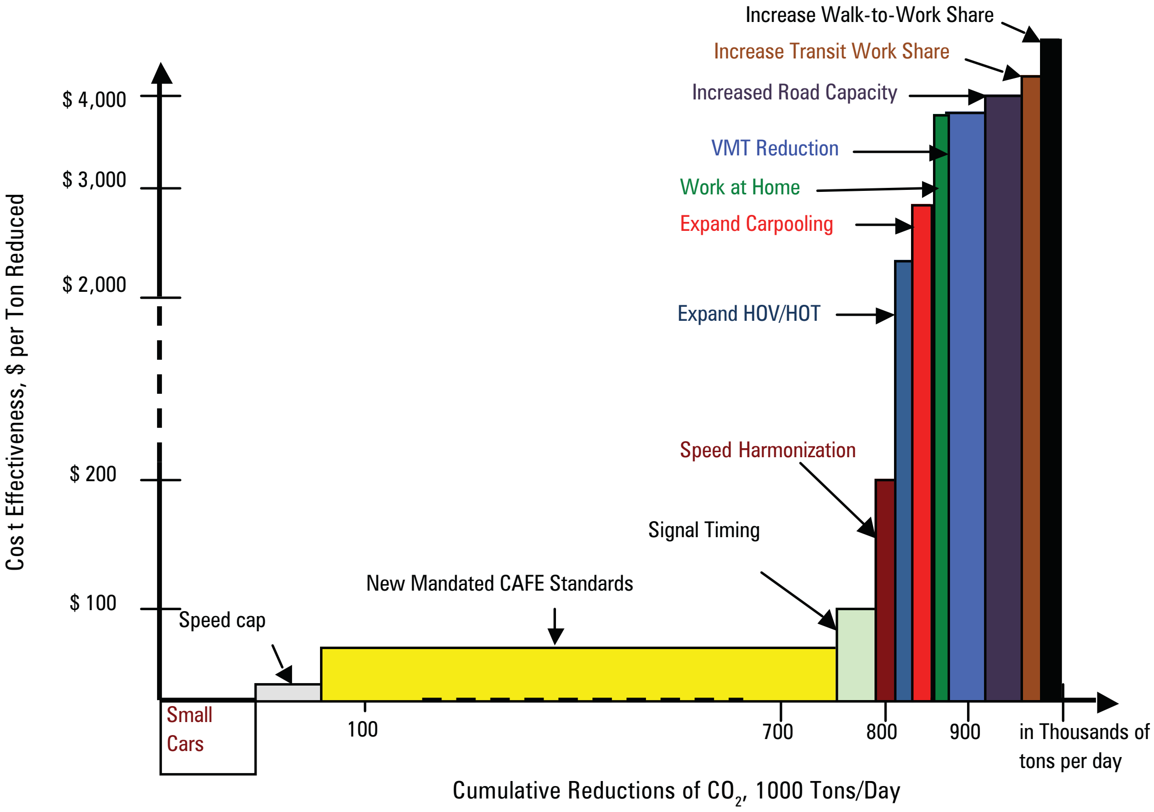


Data sources: World emissions data are from 2005; U.S. data from 2006. Since both have increased since 2005, it is likely that U.S. percentages are slightly overstated. Energy calculations based on Energy Information Administration (EIA), 2008, International Energy Outlook 2008, [prepared under the general direction of John Conti and Glen E. Sweetnam], US Department of Energy, Washington, DC, Table A-10. Transportation calculations made using data from the Transportation Energy Data Book 27, Tables 11-1, 11-5 and 11-6. Stacy C. Davis, Susan W. Diegel, and Robert G. Boundy, 2008, Transportation Energy Data Book, Edition 27, U.S. Department of Energy (DOE), Oak Ridge National Laboratory, Oak Ridge, TN.

B. Overall Findings for U.S. Regions

The following table summarizes the more detailed assessments of individual policies described below. Figure 4 shows graphically the more detailed assessments of the individual policies described below.

Figure 4: Summary of Cost-Effectiveness and CO_2 Reduction



1. Baseline forecast

If prior CAFE standards had remained in place and there were no improvements in vehicle fleet fuel economy, CO_2 emissions from VMT in the 48 regions studied would increase about 51.8% over the next several decades, in line with increases in travel.[31] This means that, for the regions studied, 2030 CO_2 transportation-related emissions would be about 2.122 million metric tons daily, about 47.2% of U.S. gasoline and diesel CO_2 emissions (4.5 MMT), 12.9% of total U.S. CO_2 emissions (16.4 MMT), and about 2.8% of world CO_2 emissions (76.9 MMT). [32]

2. Improved vehicle fuel efficiency

If fuel efficiency increases precisely in line with the 2007 amendments to CAFE standards, however, then by 2030 CO_2 emissions will only be about 1.5 million tons daily, reducing about 660,000 tons daily, which is about 30% lower than with prior CAFE standards. The overall cost-effectiveness of this policy is about $50 per ton reduced. Additional shifts to smaller cars would decrease another 39,000 tons daily, which is about a 2.7% reduction.

3. Highway system improvements

Improvements to the highway system are also capable of yielding emission reduction, but their cost-effectiveness varies. Signal timing and coordination has the potential to decrease about 35,000 tons daily, which is 2.3% of forecast CO_2 emissions, but is more expensive at $112 per ton reduced. Speed harmonization can reduce about 17,000 tons daily for a 1.1% decrease, at about $176 per ton reduced. Capacity improvements could reduce up to 60,000 tons daily for about a 4.1% reduction, but are very costly and should be evaluated on a project-by-project basis. Speed limits on freeways would reduce about 45,000 tons daily for about 3% of emissions but have high societal costs to drivers in lost time.

4. Changes in travel behavior

Actions to encourage shifts in travel behavior have mixed results. Telecommuting's potential reduction is quite low, about 8,000 tons daily, or 0.5%, and at $3,500 per ton reduced it is not very cost effective. Expanded HOV/HOT lanes could reduce up to 9,300 tons daily, or 0.6%, but because of higher construction costs (for added lanes) and limited application to larger regions its potential varies widely by region. Expanded carpooling services could decrease about 11,000 tons daily, or 0.75%, but its cost is quite high if these services are operated through government agencies. Reductions in travel through higher gasoline prices could reduce up to 58,000 tons daily, or 4%, but to do this gasoline prices would need to be near $5/gallon, making them quite costly. Improvements in transit service necessary to increase transit shares 50% would reduce about 16,000 tons daily for about a 1.1% reduction in CO_2 emissions, but the cost of service is over $4,000 per ton reduced. Finally, policies to increase walk-to-work shares by 50% would reduce about 5,000 tons daily for a 0.35% reduction in CO_2 emissions, but probably at a very high price since significant changes in land use density would be required.

Table 4: Summary of Findings

Strategy	Description	CO$_2$, K Tons/ Day	Change, K Tons/ Day	% Change	Max % Impact on Global CO$_2$ (at 6% of GGHG)	Increm. Annual Cost, $B	Cost per Ton Reduced	High Cost/Ton Regions	Low Cost/Ton Regions	Notes
Current	2005	1,391								
1. Baseline Forecast	2030, No change in average vehicle fuel economy	2,112	+ 721*	+51.8 % (-34.2 % to return to 2005)	+ 3.1 %			Phoenix Houston Raleigh Austin	Albany Rochester Milwaukee Providence	Slow growers fare better
VEHICLE TECHNOLOGY										
2.A Fuel Economy Improvements (already in place)	2030, new mandated CAFE standards	1,452	- 660**	-31.2 %	- 1.9 %	$8.540	$51.77	New York, Rochester	Phoenix, Baton Rouge, Bakersfield	Range $45-$55 per ton reduced
2.B Vehicle Size Mix	Fleet is ½ small cars, but conventional fuel	1,413	- 39***	- 2.7 %	- 0.16 %	(Likely to be a savings)				Likely to be uniform across regions
HIGHWAY IMPROVEMENTS										
3.A Signal Timing and Coordination	Improved signal coordination, arterials only.	1,475	- 35 (vs. 1,510)***	- 2.3 %	- 0.14 %	$0.983	$112	Providence Des Moines Salem	Austin Jacksonville Raleigh	Effective policy for most regions
3.B Speed Harmonization	Uniform 50 mph, peak hours, freeways	1,493	-17 (vs.1,510)*	- 1.1 %	-0.07 %	$0.733	$176	Portland OR Dayton Louisville	Austin Providence Orlando	$30-$370 per ton reduced
3.C Capacity Improvements	2030 capacity increases to remove severe congestion	1,447	- 62 (vs. 1,510)***	-4.1 %	- 0.25 %	$62.17	$3,995	Portland OR Raleigh Rochester	Ft Collins Bakersfield Cape Coral	Wide range, $1,019 to $15,200 per ton reduced
3.D Impose Speed Caps (Limits)	55 mph speed limit on freeways, peak and off-peak	1,465	- 45 (vs. 1,510)*	-3.0 %	- 0.18 %	$0.0015	$0.13	Portland OR, Providence, Tulsa	San Fran Los Angeles Phoenix	Large social costs (lost travel time)
TRAVEL BEHAVIOR										
4.A Increase Work at Home (telecommuting)	50% increase in work-at-home share, thru employer incentives	1,444	- 8***	- 0.52 %	- 0.03 %	$6.584	$3,496	Portland OR, Chicago Miami	Bridgeport Madison Jacksonville	Range $503 to $6,700 per ton reduced
4.B Expanded HOV/HOT lanes	Add 10 to 200 lane-miles (double current lane-miles)	1,443	- 9.3***	-0.64 %	- 0.04 %	$5.695	$2,462	Columbia Providence Portland OR	San Fran LA Phoenix	Range $422-$38,000
4.C Expand Carpooling Services	25% higher carpool work share, through agency vanpool services	1,441	- 11***	-0.75 %	- 0.05 %	$7.550	$2,776	Bridgeport New York Salem OR	Bakersfield McAllen Milwaukee	Wide range
4.D Reductions in Travel	5% reduction in 2030 Car/Lt Truck VMT, price increases	1,394	- 58***	-4.0 %	- 0.24 %	$56.75	$3,923	Rochester Albany Milwaukee	Austin Raleigh Houston	Small range, $3,880- $ 3,957
4.E Expand Transit Services	50% higher transit work share, through expanded service	1,436	- 16***	- 1.1 %	- 0.07 %	$16.60	$4,257	Portland OR Spokane Ogden	Bridgeport San Fran San Diego	$ Wide range, $472-$12,000
4.F Increase Walk to Work	50% increase in walk-to-work share	1,447	- 5***	- 0.35%	-0.02 %	unknown	unknown	unknown	unknown	Implementation cost is likely to be very high

*Vs 2005 Base **Vs 2030 Null ***Vs 2030 New CAFE [a]Calculated from 2005 for Policy 1, and from 2030 downward for others.

C. Baseline Forecast of Transportation CO_2 Emissions

This forecast is of CO_2 emissions from 48 regions, *if prior CAFE standards had remained and fuel efficiency had not increased*. It provides background for determining the impact of various policies on CO_2 use, including the effect of the CAFE standards passed by Congress in 2007.

The procedure used here to estimate future CO_2 emissions was straightforward. Each of the 48 regions in our study has a long-range transportation plan that forecasts population and overall travel (VMT) to (generally) 2030. We first partitioned this travel by road class, then estimated future VMT by road class and vehicle type (cars and light trucks, single-unit commercial trucks and combination commercial trucks) for each region. We obtained vehicle-mile shares by functional class and vehicle type (cars and light trucks, single-axle trucks and combination trucks) from special tabulations of the 2006 HPMS data;[33] these were assumed to be constant, within functional class, to 2030.[34] Peak-hour proportions, also from HPMS (Highway Performance Monitoring System), were also assumed to be constant to 2030.[35]

We drew the on-the-road average fuel-use rates per mile by vehicle class (20.2, 8.2 and 5.1 for cars/light trucks, single-unit commercial trucks and combos, respectively) from the Transportation Energy Data Book, 2007.[36] Using these rates, we estimated 2030 fuel consumption by vehicle class from the VMT forecasts, and then estimated CO_2 emissions from these, using standard conversion factors for CO_2 per gallon.[37] We used slightly different rates for diesel and gasoline, and assumed single-unit truck fuel use to be half gasoline and half diesel. By adding estimated emissions for each functional class and vehicle class, we were able to compute total fuel use and CO_2 emissions.

Two Harvard economists, in a paper for the Kennedy School of Government, use an addition to the standard CO_2 emissions conversion factor.[38] To account for the energy released during the refining of the oil, they tack on an extra 20% to their calculations of the CO_2 coefficient. While a few studies have followed suit, most (including studies by the EIA) do not include the additional measure for a "lifecycle coefficient." For this report, we have also not added the "lifecycle" component.

Table 5 summarizes the findings. If prior CAFE standards had remained in place and average fleet fuel economy had not increased above those standards, 2030 CO_2 emissions would be expected to increase about 51.8%, close to projected increases in VMT and fuel use.[39] This means that if fuel economy did not improve, whether as a result of tighter CAFE standards or as a response to consumer demand, and travel (VMT) continues to grow as the 48 regions forecast, these regions would be looking at approximately a 50% increase in transportation-related CO_2 emissions over the next several decades.

Table 5: Baseline Forecast of VMT, Fuel and CO_2 for 48 U.S. Urbanized Areas

Item	Units	2005	2030	Percent Change
Daily VMT	Million vehicle-miles	2,732	4,140	51.5%
Daily Fuel Use	Million gallons	154.8	234.9	51.8%
Daily CO_2	Million metric tons	1.391	2.112	51.8%

These estimates are not predictions of what will happen, but rather are forecasts based on many assumptions. Some argue that these forecasts don't reflect the nation's slowing economy, which has actually reduced VMT growth in 2008 versus 2007 when high fuel costs approaching $4/gallon dampened demand, and the 2009 recession that further dampened VMT growth despite falling gas prices.[40] But these effects may be short-lived, as travel has turned up again even though gasoline prices are now near $3/gallon. And the U.S. economy is likely to resume growing again, raising VMT.[41] Prudent estimates of a baseline future would not assume that the 2008 events would continue. While we accept that fuel efficiency improvements would likely have taken place without the tightening of CAFE standards, the point is to offer a baseline case against which we can assess the impact of such fuel efficiency improvements. Further, the use of other VMT forecasts for each region would presume knowledge better than that of the individual regions. Therefore, our estimates draw from the regions' forecasts, as reflected in their long-range plans.

Baseline forecasts of CO_2 emissions vary considerably by region, because regions have different growth rates, different proportions of traffic on road functional classes, different percentages of trucks, different transit shares and different amounts of congestion. The following table, sorted by growth rate of baseline CO_2 emissions from 2005 to 2030, shows that several fast-growing south and southeast regions (Austin, Phoenix, Raleigh, Houston) would see CO_2 emissions increases of over 100% if there had been no fleet fuel efficiency improvements beyond previous CAFE standards. On the other hand, slower-growing regions (Providence, Milwaukee, Rochester and Albany) would have seen CO_2 emissions increase less than 20%. These background circumstances, particularly projected growth rates, are critical in understanding the degree to which various mitigation strategies, discussed below, would be helpful in various regions.

Table 6: Baseline Forecasts of CO_2 with No Improvement in Average Fleet Fuel Economy

Region *(in order of Percent Change)*	2005 Daily CO_2 Emissions, K Tons	2030 Daily CO_2 Emissions, K Tons	Percent Change
Austin	15.2	36.4	139.1%
Phoenix-Mesa	48.2	108.5	125.2
Raleigh	10.5	23.4	123.9
Houston	64.4	137.1	112.8
Cape Coral	7.2	13.6	90.0
Bakersfield	11.8	21.4	82.0
Denver-Aurora	28.5	51.1	79.3
Boise City	5.5	9.8	78.2
Albuquerque	7.8	13.8	76.9
McAllen	4.5	8.0	75.0
Fort Collins	5.2	9.0	72.0
Orlando	21.3	36.4	71.0
Des Moines	5.0	8.5	70.0
Jacksonville	16.4	27.6	67.7
Ogden-Layton	5.9	9.4	59.5
Dallas-Fort Worth-Arlington	79.3	126.5	59.4
Tampa	31.5	49.0	55.9
Sacramento	27.5	42.5	54.5
Louisville	16.8	25.9	54.3
San Diego	34.4	53.0	54.1
Miami	52.6	80.4	53.0

Table 6: Baseline Forecasts of CO_2 with No Improvement in Average Fleet Fuel Economy			
Region *(in order of Percent Change)*	2005 Daily CO_2 Emissions, K Tons	2030 Daily CO_2 Emissions, K Tons	Percent Change
Minneapolis-St. Paul	28.8	43.4	50.7
Salem, OR	2.2	3.3	50.0%
Los Angeles-LB-Pom-Ontario	161.5	241.7	49.7%
Richmond-Petersburg	12.4	18.5	49.4
Seattle-Tacoma	32.9	48.5	47.6
Baton Rouge	7.3	10.7	45.0
Knoxville	14.5	20.8	43.9
Atlanta	69.7	98.4	41.1
Spokane	5.4	7.6	40.9
San Francisco-Oakland	71.2	99.7	40.0
Columbia, SC	5.3	7.4	40.0
Portland, OR	10.1	13.9	38.7
New York-Newark	137.0	188.5	37.6
Grand Rapids	10.6	14.3	36.0
Madison	7.3	9.9	35.0
Tulsa	10.7	14.3	33.0
Washington	61.9	81.5	31.6
Lancaster, PA	4.1	5.3	30.0
St. Louis	33.4	42.3	26.6
Philadelphia	52.8	66.8	26.5
Dayton	10.2	12.8	26.4
Bridgeport-Stamford	10.6	13.3	25.0
Chicago	78.7	95.3	21.0
Providence-Fall River-Newport	10.1	12.0	19.4
Milwaukee	20.7	24.5	18.4
Rochester, NY	10.7	12.4	16.2
Albany	11.5	13.3	14.9
Total for 48 Regions	1,391.0	2,111.7	Avg. 51.8%

D. New CAFE Standards

An important research question is what effect the new CAFE standards passed by Congress in 2007 will have on CO_2 emissions, compared to other policies for reducing CO_2 emissions.

Prior to 2008, the U.S. CAFE standards for cars and light trucks were established in 1975, setting 27.5 MPG (driving cycle test) for the 1990 and later model year cars; light truck standards were set at 20.0 MPG for 1990 model years with increases over time (the 2007 standard is 22.2 MPG).[42] Thus, prior to 2008 the CAFE standards law had not changed substantially in 33 years. In recent years the weighted average fuel economy of new cars has actually exceeded the standard,[43] and the overall fleet efficiency of cars approached the standard as older cars were retired. Standards for new trucks were set somewhat lower, but truck fuel economy has also improved over time.

The overall effect of increasing fuel efficiency has been dramatic. According to the Federal Highway Administration, between 1993 and 2008 overall U.S. travel (VMT) increased about 29%, but fuel use (including diesel) increased just 22%,[44] reflecting improving fuel economy. In the past several years, total fuel use has actually *declined* as the economy has slowed, and VMT has declined and fuel efficiency continued to increase. This trend, which saves fuel, has also had the effect of slowing revenues into the Highway Trust Fund just as construction prices are rising and leading to a shortfall of funds for federally aided highway and transit projects. Most individual states have seen similar trends in their state fuel tax revenues.

Table 7: U.S. Changes in Travel and Fuel Use, 1993-2008

Item	1993	2008	Percent Change
Travel (VMT), miles, trillion	2.296	2.969	29.3%
Motor Fuel, gallons, billion	140.7	171.9	22.2%

Source: Highway Statistics, Federal Highway Administration, 1993 and 2008.

In late 2007, Congress passed legislation requiring new cars and trucks to meet a CAFE standard of 35 miles per gallon by 2020.[45] The new standards also treat cars and light trucks equally, thereby dramatically increasing the requirement for light truck fuel economy to be equal to that for passenger cars.

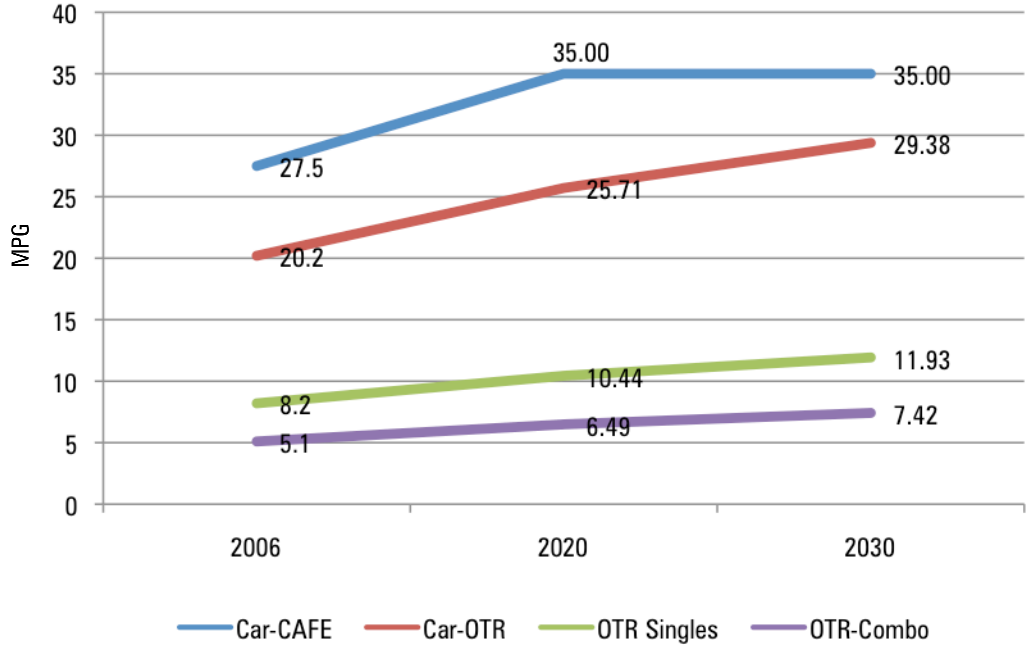
Of course, even higher standards are possible. In 2002 California passed legislation calling for even higher CAFE standards, about 43 MPG by 2020 and tighter thereafter, known as the Pavley[46] standards, and requested permission to implement it. By their estimate, the California law would produce about a 43% improvement (vs. model year 2009) in new car efficiency by 2020, compared with about a 30% improvement for the new federal standards.[47] Thirteen other states have joined California's request. The request was denied by the Bush administration, but the Obama administration EPA approved the request.[48] The EPA is also fast-forwarding the 2011 federal standards, and in April 2010 the future standard was also increased to 35.5 MPG by 2016.

The effect of the new federal CAFE standards is also expected to be dramatic. Overall, CAFE standards will increase about 27% for cars and about 58% for light trucks from prior (2007) standards. Although on-the road fuel economy is somewhat lower than the "driving cycle" CAFE, clearly the effect will be to reduce fuel use and CO_2 emissions substantially. However, the effect will vary substantially by region. In slow-growing regions the effect may even be so large as to offset background VMT growth, leading to actually *lower* CO_2 emissions in 2030 than in 2005. In fast-growing regions, the effect will be to slow the rate of growth of CO_2 emissions. The key to this change is the steady replacement of older, less fuel-efficient vehicles with newer, more efficient ones, a similar effect to improving pollution statistics for most regions.[49]

To evaluate the impact of these new standards, an important step is to estimate *on-the-road* fuel efficiency for 2030.[50] But our current data are for 2006, and government driving-cycle CAFEs, not on-the-road MPG, is specified for 2020. The prior standard was 27.5 MPG, whereas the actual on-the-road average MPG in 2006 was 20.2 MPG.[51] Because the fleet includes older, less fuel-efficient vehicles and on-the-road driving is generally less fuel-efficient than driving-cycle CAFE tests, the actual on-the-road average is expected to be below the government benchmark but move toward it over time.

In the Energy Independence and Security Act of 2007, a CAFE standard of 35 MPG is designated for all *new* vehicles by 2020. To obtain on-the road MPG figures for 2020 and 2030 from the 2006 figures, we compared the 2006 on-the-road MPG, 20.2, with a (assumed stabilized) CAFE of 27.5, for a ratio of 1.36. In other words, the CAFE rating is 36% higher than the on-the-road mileage. To estimate on-the-road MPG for 2020, we used 1.36 to deflate the 35 MPG requirement in the law. This yields 25.71. To forecast to 2030 we assumed that new cars continue to replace older ones, but that gains in fuel efficiency slow. This yields 29.38 as the on-the-road MPG for 2030. For other vehicles, we assumed that similar relationships will hold in the future, implying that those vehicles will also increase in on-the-road MPG. This yields on-the-road MPG values of 11.93 for single-unit trucks and 7.42 MPG for combination trucks. Figure 5 summarizes the procedure.

Figure 5: CAFE and MPG On the Road



An important question is the incremental cost of these improvements. Many studies, with somewhat conflicting results, have been done on this issue. In 2002 the Energy Information Administration estimated per-vehicle costs at $500–$590 for retrofitting cars not complying, compared with much lower costs of $40 to $110 for initiating new CAFE standards.[52] The U.S. Congressional Budget Office has attempted many times to quantify the costs of the new CAFE standards, including vehicle costs net of fuel cost savings for consumers.[53] The National Highway Traffic Safety Administration (NHTSA) also conducted an in-depth statistical analysis of CAFE for model years 2011 to 2015, and 2005 to 2007.[54] The estimates varied substantially, from $230 per vehicle to nearly $900 for autos.

Applying these varied findings, we have opted to use somewhat higher (conservative) estimates for incremental costs. These are first-order (manufacturer-added) costs only, which do include the fuel savings accruing to owners of higher-CAFE vehicles. Using conservative estimates of $900 per vehicle for passenger cars and light trucks, $1,500 for single-unit commercial trucks, and $3,000 for combination trucks, respectively, and applying these costs to anticipated fleet changes through 2030, the average cost will be $51.77 per ton of CO_2 emissions reduced. We then computed the number of future vehicles in each region by assuming average annual mileage per vehicle, and then estimated fuel use.[55]

An important practical question is whether drivers might increase travel to take advantage of improvements in fuel efficiency. This effect, sometimes termed the "VMT rebound" effect, has also been studied extensively.[56] NHTSA assumes -0.15 for the rebound elasticity effect in its 2008 statistical report.[57] It cites a range of 10–20% as the best rebound effect figure for use in estimation, with 25% as a maximum.[58] One review summarized the recent and most often cited research giving the short-run estimates from seven studies between 1992 and 2004 a range between 5% and 23%.[59] Long-run estimates are between 5% and 26%. All studies show the effect declining over time, possibly with rising income. The most recent study estimates a short-run effect of 5.3% and a long-run rebound effect of 22%, and predicts the effect to decline substantially with income from 2.6% and 12.1% for lower and higher incomes, respectively. This research concludes that the effect is "considerably smaller than typically assumed for policy analysis."[60]

Higher-income households already have higher mobility, and can adapt to technology more easily, so their VMT is less sensitive to changes in vehicle efficiency. Therefore, considering the latest literature and the likely declining effect over time, we assumed no VMT rebound effect to increase travel as fuel efficiency rises. This is optimistic, yielding a larger CO_2 reduction for a given CAFE change. If we had included a rebound effect, the CO_2 reductions might be reduced 10 to 15%.

Applying our estimates of on-the-road fuel efficiencies to 2030 data on VMT by vehicle type and functional class, the following table summarizes the overall findings.

Table 8: Effect of New CAFE Standards on CO_2 Emissions

Item	2005	2030 Baseline Forecast	% Change	2030, New CAFEs	% Change from 2030 Baseline	Daily CO_2 Reduction, K Tons
Daily VMT, million	2,732	4,140	51.5%	4,140		
Daily fuel, million gal	154.8	234.9	51.8	161.5	-31.2%	
Daily CO_2, million tons	1.391	2.112	51.8	1.452	- 31.2%	660
Annual cost, $ billion						8.540
Cost per ton reduced						$51.77
Daily VMT, million*	2,732	4,140	51.5	4,139		
Daily fuel, million, gal*	154.8	234.9	51.8	142.6	-39.3%	
Daily CO_2, million tons*	1.391	2.112	51.8%	1.282	-39.3%	830

*(with approximate "Pavley": 45 MPG by 2030)

Overall, the new CAFE standards passed in 2007 will result in about a 4.4% increase in CO_2 emission versus 2005 (including growth in travel), or about 31.2% *below* what the prior standards would have produced. So, to say it another way, the new CAFE standards will hold fuel use and CO_2 emissions at close to their current (2005) levels, even as VMT continues to rise. If standards were tightened even further to California levels (Pavley Law) and applied to all of our 48 regions, the further reduction would be about 170,000 tons daily (830,000–660,000), or an additional 8.1% of baseline emissions.[61] The decrease would be quite small, most regions being within 1 or 2 percentage points from the average 8.1% reduction. Accelerating the current CAFE standards to 2016 rather than 2020, as has been implemented by the Obama administration, is likely to reduce about one-fifth of that, or about 1.6% of baseline emissions by 2030.

The result of this policy varies somewhat by region (Table 9). Slower-growing regions might actually see *less* CO_2 emissions than in 2005 since the effect of the new CAFE standards would more than offset the regional growth in VMT. For instance, in 2005 Chicago was emitting about 78,700 tons of CO_2 daily, but this would *decline* to 65,500 tons daily with the new CAFE standards, even though the region is growing (slowly). On the other hand, fast-growing regions might not show a reduction in CO_2, but would show significantly smaller CO_2 increases than in the baseline forecast. And in all regions, the overall cost per ton of CO_2 reduced is in the $50 range. While high, this is still more cost effective than many of the other policies considered in this report.

Table 9: Effect of New CAFE Standards on CO_2 Emissions

Region (in order by Percent Change in CO_2)	2005 Daily CO_2, K Tons	2030 Baseline Forecast of CO_2, K Tons	2030 Daily CO_2, With New CAFE, K Tons	CO_2 Reduction versus Baseline, K Tons	% Change vs. 2005	Cost/ Ton Reduced, $
Austin	15.2	36.4	25.0	11.4	64.4	53.69
Phoenix-Mesa	48.2	108.5	74.6	33.9	54.8	45.72
Raleigh	10.5	23.4	16.1	7.3	54.0	50.42
Houston	64.4	137.1	94.2	42.8	46.3	51.09
Cape Coral	7.2	13.6	9.4	4.3	30.6	51.82
Bakersfield	11.8	21.4	14.7	6.7	25.1	46.08
Denver-Aurora	28.5	51.1	35.1	16.0	23.3	54.27
Boise City	5.5	9.8	6.7	3.0	22.5	53.41
Albuquerque	7.8	13.8	9.5	4.3	21.6	48.62
McAllen	4.5	8.0	5.5	2.5	20.3	50.99
Fort Collins	5.2	9.0	6.2	2.8	18.2	54.13
Orlando	21.3	36.4	25.1	11.4	17.6	51.56
Des Moines	5.0	8.5	5.9	2.7	16.9	52.79
Jacksonville	16.4	27.6	18.9	8.6	15.3	51.49
Ogden-Layton	5.9	9.4	6.5	3.0	9.7	46.84
Dallas-Fort Worth	79.3	126.5	86.9	39.5	9.6	50.09
Tampa	31.5	49.0	33.7	15.3	7.2	53.68
Sacramento	27.5	42.5	29.2	13.3	6.3	53.10
Louisville	16.8	25.9	17.8	8.1	6.1	47.31
San Diego	34.4	53.0	36.4	16.6	5.9	54.23
Miami	52.6	80.4	55.3	25.1	5.2	52.48
Minneapolis-St. Paul	28.8	43.4	29.8	13.6	3.6	52.80
Salem, OR	2.2	3.3	2.3	1.0	3.1	49.15
Los Angeles-Long Beach	161.5	241.7	166.1	75.5	2.9	52.88
Richmond-Petersburg	12.4	18.5	12.7	5.8	2.7	52.07
Seattle-Tacoma	32.9	48.5	33.4	15.2	1.5	51.69
Baton Rouge	7.3	10.7	7.3	3.3	-0.3	45.90
Knoxville	14.5	20.8	14.3	6.5	-1.0	50.91
Atlanta	69.7	98.4	67.6	30.7	-3.0	50.99
Spokane	5.4	7.6	5.3	2.4	-3.1	50.45
San Francisco-Oakland	71.2	99.7	68.6	31.2	-3.7	53.59
Columbia, SC	5.3	7.4	5.1	2.3	-3.8	49.37
Portland, OR	10.1	13.9	9.6	4.4	-4.7	52.85
New York-Newark	137.0	188.5	129.6	58.9	-5.4	55.19

Table 9: Effect of New CAFE Standards on CO_2 Emissions

Region (in order by Percent Change in CO_2)	2005 Daily CO_2, K Tons	2030 Baseline Forecast of CO_2, K Tons	2030 Daily CO_2, With New CAFE, K Tons	CO_2 Reduction versus Baseline, K Tons	% Change vs. 2005	Cost/ Ton Reduced, $
Grand Rapids	10.6	14.3	9.9	4.5	-6.5	50.76
Madison	7.3	9.9	6.8	3.1	-7.2	48.10
Tulsa	10.7	14.3	9.8	4.5	-8.6	52.18
Washington	61.9	81.5	56.0	25.5	-9.5	54.41
Lancaster, PA	4.1	5.3	3.7	1.7	-10.6	51.22
St. Louis	33.4	42.3	29.1	13.2	-12.9	49.48
Philadelphia	52.8	66.8	45.9	20.9	-13.0	51.38
Dayton	10.2	12.8	8.8	4.0	-13.1	49.05
Bridgeport-Stamford	10.6	13.3	9.1	4.1	-14.0	52.23
Chicago	78.7	95.3	65.5	29.8	-16.8	48.51
Providence-Fall River	10.1	12.0	8.3	3.8	-17.9	56.00
Milwaukee	20.7	24.5	16.8	7.7	-18.6	50.52
Rochester, NY	10.7	12.4	8.5	3.9	-20.1	56.01
Albany	11.5	13.3	9.1	4.1	-21.0	53.02
Totals/Weighted Avg.	1,391.0	2,111.7	1,451.8	659.9	4.4	$ 51.77

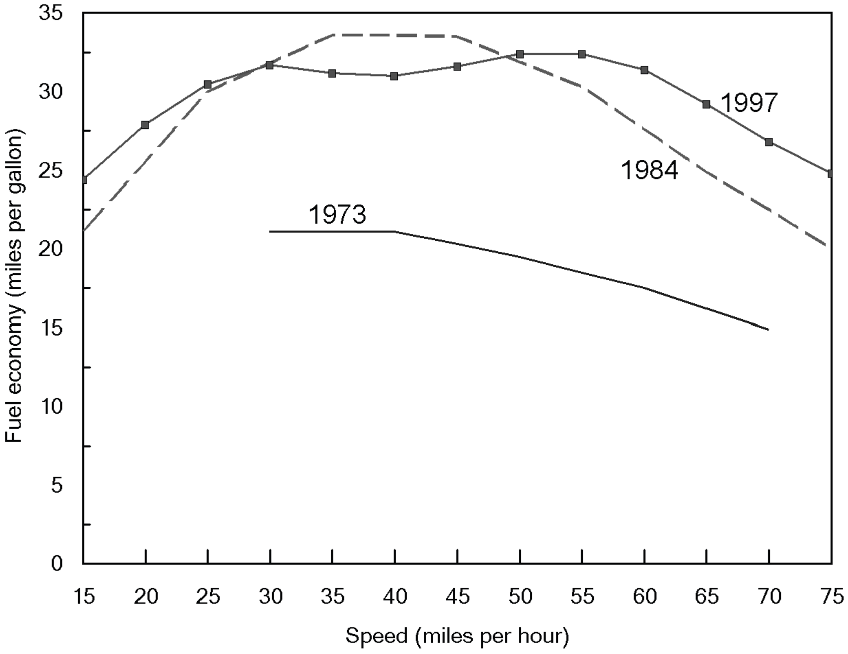
This table suggests that fast-growing regions (e.g., Austin, Phoenix, Raleigh and Houston) need to determine the importance of CO_2 reduction in their plans, and if important, identify actions that might reduce it in a cost-effective manner. On the other hand, slower-growing regions may have the luxury of time to determine what, if any, additional actions might be needed.

This analysis has many limitations. It does not consider other factors that might affect CO_2 emissions, particularly changes in regional growth rates, rising congestion, changes in gasoline prices, slowdowns in vehicle turnover, VMT rebound effects of rising fuel efficiency, major modal shifts, rising truck shares, energy prices or economic shifts. Some applicable elasticity analyses are fuel consumption with respect to price and the elasticity of annual vehicle mileage with respect to per-mile vehicle operating costs.[62] Elasticity of vehicle travel with respect to fuel price has been estimated at -0.15 in the short run and -0.3 over the long run.[63] Some of these actions would increase fuel efficiency, while others might worsen it. While some of these effects are covered below, the effects of most seem to be quite small relative to the rising CAFE standards. Therefore, we view this assessment as reasonable.

E. Signal Timing and Coordination

From an air quality perspective, signal timing improvements save fuel and air pollution by reducing vehicle idling delays and improving overall travel speeds. Fuel economy varies by speed in an inverted U-shaped fashion, with maximum fuel economy for more modern vehicles generally in the 45-55 mph range (Figure 6). This relationship means that raising low speeds (those below about 45 mph) will generally result in less emissions per mile traveled, while reducing high speeds (those over about 55 mph) will generally result in less emissions per mile. Since most urban arterial traffic speeds average well below 35 mph, signal timing improvements usually result in higher overall travel speeds and therefore less fuel use and less pollution. There are, of course, also some significant time savings benefits associated with raising arterial traffic speeds.

Figure 6: Fuel Economy by Speed, 1973, 1984 and 1997 Studies



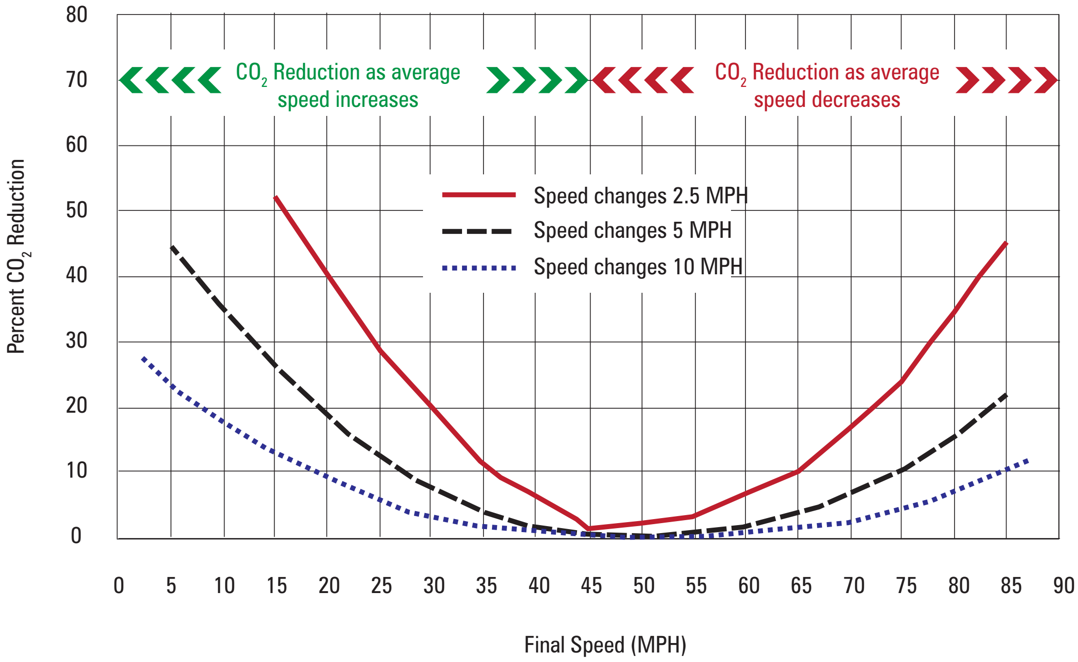
Source: Transportation Energy Data Book, Edition 27, Figure 4.2

These effects tend to result in a relatively small improvement in the flow of traffic, but since they affect both peak and off-peak drivers, the impact adds up quickly. About 27% of urban weekday traffic (VMT) in the 48 cities reviewed is on arterials and collectors.[64] And of course signal improvements would also apply to weekend traffic as well as to both cars and trucks, so the proportion of traffic exposed to signal improvements can approach 40%. Signalization projects also have other benefits (e.g., reduced travel time, lower operating costs and reduced accidents), so CO_2 reduction is one of many reasons to optimize signalization. However, they might also raise VMT (a sort of rebound effect) but that is likely to be minor.

Signal improvements are not as visible as major capital actions and so are sometimes not given the priority they deserve. Ironically, this may mean a large overlooked potential for improvement. A recent review of the status of signals nationwide indicated that of the 300,000 traffic signals currently in use, over 75% could easily be improved in flow characteristics, either through updating equipment or adjusting their timing.[65] And the potential benefits for these improvements can be quite substantial. According to the FHWA's Arterial Management Benefits database, basic signal improvements can achieve a 15 to 20% reduction in delay, while more advanced improvements, such as automated signal controls, can reduce delay by up to 40%.[66]

Since signalized intersections tend to be on the arterial system where speed limits are mostly below 45 mph, these reductions in delay generally have a positive effect on fuel economy, which in turn has a positive effect on CO_2 emissions. In an analysis of typical traffic conditions in Southern California, one study found that CO_2 emissions could be reduced up to 25%, 45% and 60% by increasing arterial speeds by 2.5 mph, 5 mph and 10 mph, respectively (Figure 7).[67] It also found that CO_2 emissions could be reduced some 45% by allowing traffic to travel at steady, optimal speeds.[68]

Figure 7: CO_2 Emissions Reduction from Speed Changes



Source: Matthew Barth and Kanok Boriboonsomsin, 2008, "Real-World CO_2 Impacts of Traffic Congestion," Paper for the 87th Annual Meeting of Transportation Research Board, Washington, D.C., p. 11.

Because this analysis is more detailed than the prior assessment, its estimates differ slightly from the prior analyses. See the appendix for additional details. The following basic steps were used in our analysis. First, we estimated CO_2 emissions for 2030 conditions with no changes in signalization (using forecasts of travel, but assuming increasing congestion). Next, we determined the CO_2 emissions for 2030 conditions with signalization improved. We assumed an improvement of 15% in peak-hour driving speeds, resulting in a 15% improvement in each region's Travel Time Index.[69] For off-peak hours, we assumed an improvement of 10% in driving speeds. But we limited the flow improvements to just the arterial system (principal arterials and minor arterials), since these have most of the major urban signals.

The direct costs of traffic signal timing improvements are also relatively inexpensive and include the capital costs of installing the signals themselves, the costs of timing the signals (which must be rechecked/retimed every three to five years), and the costs of maintaining the signals (one technician per 60 signals).[70] Even the cost of new signals can be much less than widenings or lane additions. The cost of improving signals is estimated from the 2007 National Traffic Signal Report Card at $13,500 every 10 years for intersection controllers, $3,000 every three years per intersection for timing, and a $60,000/year technician for every 60 traffic signals.[71] We calculated the number of signalized intersections in each urbanized area using arterial signal data from the TLC2 report[72] and extended it based on the city shares of arterials from FHWA data.[73] These costs might be low since they do not include the cost of the signals themselves; we assumed that signals would be required in any case, so the appropriate cost is the incremental government cost of improving their timing and coordination.

The following tables summarize our findings. For the 48 cities reviewed, improving signalization saves about 3.9 million gallons of fuel daily, which translates into about 35,000 tons of CO_2 emissions reduced daily. This is about 2.3% of the baseline forecast of total daily emissions, 1,510 KT. Using average incremental costs for signalization improvements, the annual government cost to do this is $983 million, or about $112 per ton reduced. However, this is only part of the picture. Motorist delay and fuel use are also reduced. We estimate that drivers in these 48 cities save over $20 billion annually in the value of their time, or an average of $2,307 saved per ton of CO_2 reduced. So the benefits of improved signalization are substantial and arguably provide a much better reason for implementation that as a fairly expensive means to reduce CO_2 emissions.

Table 10: CO_2 Reduction from Improved Signalization

Item	2005	2030 with Current Signals	2030 with Improved Signals	Percent Change from 2030	Daily Reduction, from 2030	Cost/ CO_2 Ton Reduced
Daily VMT, million	2,732	4,140	4,140	0%	0	
Daily fuel, million gallons	154.8	168.0*	164.1	-2.3%	3.9	
Daily CO_2, million tons	1.391	1.510*	1.475	-2.3%	0.035	
Annual cost, $million			$983			$112

*Differs slightly from other tests because of greater calculation detail.

The following table shows the details of decrease in emissions for each of the 48 regions. Most regions also show a reduction in the range of about 2 to 3%. However, the costs per ton of CO_2 reduced vary widely, from a low of $30 per ton reduced in Austin to $371 per ton reduced in Providence. This variation is dependent upon the numbers of signals in the urbanized area and also the traffic volumes that would be affected by signal improvements.

Table 11: Effects of Improved Signalization on CO_2 Emissions by Region

Region (in order by Percent Change in CO_2)	2005 Daily CO_2, Tons, K	2030 Current Signals, Daily CO_2, Tons, K	2030 Improved Signals, Daily CO_2, Tons, K	Reduction vs. 2030 Daily CO_2, Tons, K	% Change vs. 2030 Current Signals	Annual Cost to Gov't per Ton Reduced, $	Annual Cost to Drivers per Ton reduced, $
Dallas-Fort Worth	79.3	89.5	87.8	1.7	-1.9%	$92	-$2,465
San Diego	34.4	37.6	36.9	0.7	-1.9	110	-2,446
Phoenix-Mesa	48.2	76.9	75.4	1.5	-1.9	62	-2,672
New York-Newark	137.0	134.4	131.5	2.9	-2.1	186	-2,873
Houston	64.4	96.9	94.9	2.0	-2.1	80	-2,226
Dayton	10.2	8.9	8.7	0.2	-2.1	136	-1,438
Bakersfield	11.8	14.8	14.5	0.3	-2.1	89	-2,459
McAllen	4.5	5.5	5.4	0.1	-2.1	175	-1,481
Salem, OR	2.2	2.3	2.2	0.0	-2.1	288	-1,952
Philadelphia	52.8	47.1	46.0	1.0	-2.2	223	-2,544
St. Louis	33.4	29.6	29.0	0.7	-2.2%	$163	-$1,461
Tampa	31.5	34.8	34.0	0.8	-2.2	77	-2,156
Milwaukee	20.7	17.0	16.6	0.4	-2.2	250	-2,111
Portland, OR	10.1	9.8	9.6	0.2	-2.2	265	-2,316

Table 11: Effects of Improved Signalization on CO_2 Emissions by Region

Region (in order by Percent Change in CO_2)	2005 Daily CO_2, Tons, K	2030 Current Signals, Daily CO_2, Tons, K	2030 Improved Signals, Daily CO_2, Tons, K	Reduction vs. 2030 Daily CO_2, Tons, K	% Change vs. 2030 Current Signals	Annual Cost to Gov't per Ton Reduced, $	Annual Cost to Drivers per Ton reduced, $
Providence-Fall River	10.1	8.3	8.1	0.2	-2.2	371	-2,053
Jacksonville	16.4	19.3	18.9	0.4	-2.2	49	-1,397
Richmond-Petersburg	12.4	12.8	12.5	0.3	-2.2	134	-1,625
Rochester, NY	10.7	8.7	8.5	0.2	-2.2	131	-2,082
Albany	11.5	9.2	9.0	0.2	-2.2	121	-1,939
Albuquerque	7.8	9.5	9.3	0.2	-2.2	101	-2,302
Tulsa	10.7	9.9	9.7	0.2	-2.2	163	-1,944
Grand Rapids	10.6	10.0	9.7	0.2	-2.2	114	-2,436
Baton Rouge	7.3	7.3	7.2	0.2	-2.2	190	-2,149
Columbia, SC	5.3	5.1	5.0	0.1	-2.2	206	-1,714
Raleigh	10.5	16.4	16.1	0.4	-2.2	45	-1,914
Knoxville	14.5	14.5	14.2	0.3	-2.2	70	-1,508
Des Moines	5.0	5.9	5.8	0.1	-2.2	265	-2,011
Cape Coral	7.2	9.6	9.4	0.2	-2.2	70	-1,885
Lancaster, PA	4.1	3.7	3.6	0.1	-2.2	257	-1,977
Boise City	5.5	6.8	6.6	0.1	-2.2	150	-2,239
Fort Collins	5.2	6.3	6.1	0.1	-2.2	121	-2,404
Seattle-Tacoma	32.9	34.9	34.1	0.8	-2.3	148	-2,384
Sacramento	27.5	29.6	29.0	0.7	-2.3	70	-2,328
Orlando	21.3	25.7	25.2	0.6	-2.3	74	-1,908
Bridgeport-Stamford	10.6	9.3	9.0	0.2	-2.3	148	-1,934
Austin	15.2	25.3	24.7	0.6	-2.3	30	-1,688
Spokane	5.4	5.3	5.2	0.1	-2.3	283	-2,299
Ogden-Layton	5.9	6.6	6.4	0.1	-2.3	106	-1,387
Madison	7.3	6.9	6.7	0.2	-2.3	125	-1,516
Los Angeles-Long Beach	161.5	179.6	175.3	4.3	-2.4	104	-2,933
Minneapolis-St. Paul	28.8	31.0	30.3	0.7	-2.4	163	-2,305
Denver-Aurora	28.5	36.3	35.5	0.9	-2.4	90	-2,598
Louisville	16.8	18.0	17.5	0.4	-2.4	67	-1,393
San Francisco-Oakland	71.2	72.7	70.8	1.9	-2.6	72	-2,217
Washington	61.9	59.6	58.0	1.6	-2.7	85	-2,874
Chicago	78.7	70.2	68.2	2.0	-2.9	153	-2,307
Atlanta	69.7	71.9	69.8	2.1	-2.9	59	-1,577
Miami	52.6	58.2	56.5	1.7	-3.0	60	-1,681
Total/Weighted Avgs.	1,391.0	1,509.6	1,474.5	35.1	-2.3%	$112	$ -2,307

F. Capacity Improvements

Improvements in road capacity have long been recognized as an important way of improving transportation flow and efficiency in urban areas. They were a major part of highway plans for urban areas in the 1970s–1990s, providing significant increases in capacity in most regions. However, they also have significant costs and environmental impact, and also may induce some additional travel that fills them sooner than predicted.

Although proposals for major road improvements have declined in recent years and they are increasingly difficult to implement given environmental and funding issues, they still form a significant portion of the short-range and long-range transportation plans of most regions. A recent review of the plans for 22 large regions found that major highway improvements, including capacity-increasing actions, constituted about 58% of planned short-term (three- to six-year) expenditures, and 57% of long-term (20+) year expenditures.[74] This study also found that among the 22 large regions, 17 were planning freeway widenings, 12 new toll sections, and 12 HOV/HOT lanes. For the state highway systems, capacity and bridge improvements also constitute about 55% of their combined annual highway budgets of about $99.6 billion.[75]

The costs of capacity improvements can be substantial. In a 2005 Reason Foundation study we estimated that about $533 billion would be needed over 25 years to remove severely congested sections from the nation's 403 urbanized areas.[76] The report used FHWA unit cost data, ranging from about $15 million per lane-mile for new construction in large regions down to about $500,000 per lane-mile for minor improvements in smaller regions, based on data collected in the 1990s. However, highway construction costs have increased sharply since then. The Federal Highway Administration has recently updated its earlier costs and raised them significantly (by about a factor of 2.5) to a high of over $50 million per lane-mile added to freeways in high-cost areas, ranging down to about $2 million per lane-mile added on arterials and collectors in lower-cost areas.[77] An influential 2003 book, *Megaprojects and Risk*, reviewed over 200 highway projects around the world, and found that highway projects' final cost tended to come in at about 40% over initial cost estimates, while transit project costs were about 106% over the initial estimate.[78] A recent monthly review of cost indices found that overall highway construction prices rose 22 percent in 2008 versus 2007, and 95% over 10 years, but prices may be moderating somewhat now.[79] Another Reason Foundation report examining innovative highway designs found costs for tunnels and cut-cover projects could be as high as $100 million per lane-mile.[80] In short, highway construction prices are now about double what they were just a decade ago. Although prices moderated in 2007–09, they are now rising again but not as fast as in the past decade. On balance, a more modest rate of increase seems more likely going forward.

Although increasing capacity can be quite expensive, it raises speeds, thereby reducing energy used and emissions created as well as travel time. Widening projects also have other benefits (lower operating costs, reduced accidents), so there are other reasons to do them than just CO_2 reductions. As with signal optimization, increases in capacity also may attract some new traffic as getting around becomes less onerous. This new traffic may be additional trips induced by the added highway capacity or simply latent demand that is now being met.[81]

Since regions vary widely in the amount and location of congestion and the prices of construction, we would expect that the costs of improving CO_2 emissions through this policy would vary widely by region, and also by individual project within a region. This is particularly true for high-payoff projects such as bottleneck removals, intersection treatments and other similar short-distance/high-impact projects. Therefore the assessment below should be taken only as a high-level guide to the potential for CO_2 reduction in each area through capacity increases. Each region should sift through potential projects and conduct individual project-level assessments on major projects to determine project worthiness.

The goal of this assessment is to determine the cost-effectiveness of reducing CO_2 emissions by adding road capacity sufficient to remove severe congestion from the major road systems in urbanized areas. We used the following basic steps in the analysis. (See the appendix for additional detail.) First, we determined the CO_2 emissions for 2030 conditions with no changes in highway capacity, using forecasts of travel and congestion, along with fuel efficiency rates by speed.[82] Next, we determined the CO_2 emissions for 2030 conditions, with capacity added (using capacity data from our earlier Reason Foundation's report) such that severe congestion is removed.[83] Finally, we determined the cost per ton of decreasing CO_2 emissions through congestion removal. We drew costs per lane-mile from the 2006 HERS-ST data from the Federal Highway Administration.[84] Unit costs vary from about $50 million/lane-mile added for Interstates in high-cost areas, down to about $2 million per lane-mile added for arterials in low-cost areas.

Tables 12, 13 and 14 summarize our results. For the 48 regions reviewed, eliminating severe congestion would (in 2030) save about 6.94 million gallons of fuel daily, which translates into a reduction of about 62,250 tons of CO_2 emissions daily. This is about 4.1 percent of the baseline forecast of total emissions, 1,510 KT. Using the revised (significantly increased) estimates of costs of construction from FHWA, the cost to do this is a little over $1,243 billion ($62.17 billion annually over 20 years), or about $3,995 per ton of CO_2 reduced. These costs do not include the very rapid increases of the last decade, nor the more recent declines in prices, so on balance they seem reasonable.

Table 12: CO_2 Reduction from Removing Severe Congestion

Item	2005	2030 With Congestion	2030 Without Congestion	% Change from 2030	Daily Reduction	Cost/ CO_2 Ton Reduced
Daily VMT, million	2,732	4,140	4,140	0%	0	
Daily fuel, million gal	154.8	*168.0	161.1	-4.1%	6.94	
Daily CO_2, mill tons	1.391	*1.510	1.447	-4.1%	0.062	
Annual cost, $billion			$ 62.17			$ 3,995

*Differs slightly from prior tables due to more detailed calculations.

As expected, the costs vary widely by road class. Interstate and freeway projects are the most expensive, but also have the most congested traffic and hence the most potential benefits (reduced travel time, lower operating costs, reduced fatalities, increased accessibility and reduced CO_2 emissions). From a CO_2 reduction standpoint, however, these projects cost the most per ton reduced, $9,486 and $4,245 per ton reduced, respectively. Projects on minor arterials seem to offer the most cost-effective potential, about $72 per ton reduced, because the work is much less costly. However, the total decrease here is limited to about 8,300 tons/day, about 0.5% of emissions. While the lowest level projects (local streets) also provide cost effective CO_2 removal, they do not carry much traffic and so provide fewer of the other benefits of congestion relief. On the other hand, arterials bear a heavy traffic load and have multiple points along them where capacity additions could provide significant relief. Arterials also tend to have the most stop-and-go traffic conditions that increase idling times in addition to lower fuel efficiencies.[85] It is likely that specific projects on all systems, but especially on the arterials, could provide cost-effective CO_2 reductions well below average.

Table 13: CO_2 Reduction from Removing Congestion

	Interstates	Other Freeways/ Expressways	Other Principal Arterials	Minor Arterials	Collectors	Local Streets
Daily CO_2 Reduction K Tons	16.6	9.2	13.9	8.3	6.3	8.0
Cost to Remove Congestion, $Billion	$786	$194	$121	$2.99	$129	$9.290
Cost per Ton of CO_2 Reduced over 20 Years	$9,486	$4,245	$1,744	$72	$4,112	$231

The following table shows more details, in terms of reduction and cost-effectiveness by region. Emission reductions vary widely by region, depending on the location and cost of the lane-miles actually needed to eliminate severe congestion, as well as the level of highway usage and the magnitude of current congestion. The regions with the lowest cost per ton reduced tend to be smaller regions (Ft. Collins, Bakersfield, Salem and Cape Coral) where costs of construction are typically lower, but some very large regions (L.A., Tampa, Atlanta and D.C.) also have costs per ton reduced lower than average. Five regions (Miami, Portland, Raleigh, Tulsa and Rochester) all have very high costs per metric ton reduced, at $10,000 or greater.

Table 14: Effects of Removing Congestion on CO_2 Emissions by Region

Region (in order by percent change)	2005 Daily CO_2, Tons, K	2030 with Congestion, Daily CO_2, Tons, K	2030 without Congestion, Daily CO_2, Tons, K	Reduction from Congestion Removal, Tons, K	Percent Change, with vs. without Congestion	Annual Cost over 20 Years per Metric Ton Reduced, $
Fort Collins	5.24	6.26	6.22	0.04	-0.68	$1,019
Rochester, NY	10.66	8.65	8.59	0.06	-0.74	$11,791
Boise City	5.48	6.77	6.72	0.05	-0.74	$4,277
Des Moines	5.01	5.91	5.86	0.04	-0.75	$9,048
Ogden-Layton	5.92	6.57	6.52	0.05	-0.75	$7,473
Baton Rouge	7.35	7.33	7.27	0.06	-0.82	$6,953
Madison	7.33	6.85	6.79	0.06	-0.87	$7,561
Spokane	5.42	5.29	5.24	0.05	-0.91	$6,539
Dayton	10.15	8.89	8.81	0.08	-0.92	$5,406
Tulsa	10.75	9.94	9.84	0.10	-0.98	$10,047
Lancaster, PA	4.10	3.73	3.69	0.04	-1.00	$5,920
Columbia, SC	5.29	5.12	5.07	0.05	-1.03	$4,522
Bakersfield	11.77	14.79	14.64	0.15	-1.03	$1,143
Richmond-Petersburg	12.38	12.79	12.66	0.13	-1.05	$1,339
Albany	11.55	9.19	9.09	0.10	-1.05	$7,098
McAllen	4.54	5.54	5.48	0.06	-1.05	$5,866
Knoxville	14.48	14.50	14.35	0.16	-1.07	$5,144
Salem, OR	2.20	2.26	2.24	0.02	-1.08	$1,637
Jacksonville	16.44	19.30	19.08	0.22	-1.13	$3,272
Providence-Fall River	10.07	8.31	8.22	0.10	-1.16	$9,345
Grand Rapids	10.55	9.96	9.84	0.12	-1.16	$1,767
Milwaukee	20.69	17.02	16.82	0.20	-1.19	$4,910
Raleigh	10.47	16.41	16.21	0.21	-1.27	$12,382
Cape Coral	7.17	9.64	9.52	0.12	-1.29	$1,316
Albuquerque	7.77	9.50	9.37	0.13	-1.36	$4,253
Louisville	16.77	17.96	17.67	0.29	-1.62	$4,734
Austin	15.21	25.31	24.87	0.44	-1.72	$3,954
Orlando	21.31	25.74	25.25	0.48	-1.88	$1,547
Bridgeport-Stamford	10.60	9.26	9.08	0.18	-1.96	$3,297
St. Louis	33.39	29.63	29.03	0.61	-2.05	$4,651
Portland, OR	10.05	9.78	9.57	0.20	-2.06	$15,215

Table 14: Effects of Removing Congestion on CO_2 Emissions by Region

Region (in order by percent change)	2005 Daily CO_2, Tons, K	2030 with Congestion, Daily CO_2, Tons, K	2030 without Congestion, Daily CO_2, Tons, K	Reduction from Congestion Removal, Tons, K	Percent Change, with vs. without Congestion	Annual Cost over 20 Years per Metric Ton Reduced, $
Sacramento	27.52	29.63	28.99	0.64	-2.15	$4,274
Tampa	31.46	34.80	34.04	0.76	-2.19	$1,802
Philadelphia	52.80	47.07	45.84	1.23	-2.61	$6,147
Minneapolis-St. Paul	28.80	31.00	29.93	1.07	-3.46	$7,393
Phoenix-Mesa	48.20	76.88	74.20	2.68	-3.49	$4,064
Houston	64.42	96.94	93.54	3.39	-3.50	$3,952
San Diego	34.39	37.56	36.20	1.36	-3.61	$5,719
New York-Newark	136.96	134.39	129.48	4.91	-3.65	$3,739
Dallas-Fort Worth	79.33	89.53	86.16	3.37	-3.76	$4,541
Denver-Aurora	28.48	36.35	34.88	1.47	-4.04	$4,573
Miami	52.56	58.25	55.64	2.60	-4.47	$10,000
Seattle-Tacoma	32.88	34.93	33.26	1.67	-4.79	$1,686
Atlanta	69.74	71.92	67.89	4.03	-5.61	$2,873
San Francisco-Oakland	71.23	72.67	68.02	4.65	-6.40	$3,917
Washington	61.92	59.63	55.75	3.88	-6.51	$3,126
Chicago	78.73	70.22	65.48	4.74	-6.75	$5,579
Los Angeles-L Beach	161.48	179.60	164.42	15.18	-8.45	$2,366
Totals/Weighted Average	1,391.02	1,509.57	1,447.32	62.25	-4.12	$3,995

G. Speed Controls

We consider two forms of speed controls: speed capping and speed harmonization. In speed capping, speed limits are capped well below their current levels, like the 55 national speed limit set following the Arab oil embargo in the 1970s. These policies are similar to common individual road speed limits but apply to groups of roads within a given geography. However they have proved unpopular for enforcement, economic and privacy reasons; the national speed limit law was repealed in 1995. Nevertheless most local governments still use local speed limits for safety and control purposes. When average speeds are above 45 MPH, reducing them will generally result in lower per-mile fuel consumption and emissions. The effect is largest if average speeds are over 65 MPH initially, and is quite small if average speeds are initially 45-65 MPH. So when average speeds are high, reducing them can both save energy and reduce emissions and may reduce accidents and accident severity. Speed reductions do, however, have an adverse impact on the flow of goods and people, and the cost to drivers in added travel time is quite significant.

Reducing speed limits on specific freeway-like roads for all hours or just during peak or congested periods is quite inexpensive. These costs include the capital costs of installing the signage itself (which can be simple road signs or elaborate electronic, variable message signs) and the costs of operating and maintaining the signs. (Enforcement, which varies significantly, is likely to be low overall.) These costs range from as little as $75 to replace an existing speed limit sign to $200,000 plus to install an overhead electronic variable message sign.[86]

In speed harmonization, speed limits are lowered and made uniform by lane or direction during periods of congestion to keep traffic flowing more smoothly. Speed harmonization is being studied in Europe, where it is referred to as “intelligent speed assistance” (ISA). ISA is usually not an intervening system (mandatory in-car enforcement of speed limit), but is rather a group of services (signs, messages, etc.) that inform the driver of the proper speed limit and possibly warn or discourage the driver from exceeding the limit.[87] Ten European governments have experimented with ISA systems.[88] Most of the experiments have been for controlled Interstate-like roads. However, Sweden is the only European country to mandate the system; it presented this policy to the public in its transportation strategy plan for 2005.[89]

In the U.S., speed harmonization and/or variable speed limits are quite rare and are mostly rural projects focused on safety, weather or terrain, primarily in off-peak hours rather than during congestion. The Washington State DOT initiated a project in 1997–1998 which reads road conditions, estimates a speed limit no greater than a given maximum, checks with WSDOT for approval and posts the limit on a variable sign.[90] For the 40-mile stretch of I-90 over Snoqualmie Pass, the project cost was about $5 million. In Colorado a dangerous curve over a mountain pass where several severe accidents had taken place prompted the Colorado DOT to establish a speed warning system in 1996.[91] This project involves a single curve on a downhill slope that tightens seven to eight degrees on I-70 in Glenwood Canyon, Colorado; it cost between $25,000 and $30,000. There are other examples of costs for variable speed systems in Seattle, California and Utah. And of course some urban regions have message boards that warn of incidents or post advisory speeds. But there are few, if any, examples of the ISA variety in the United States.

To undertake the assessment, we used the following basic steps. (See the appendix for additional detail). First we estimated the CO_2 emissions for 2030 conditions, with no changes in highway speed limits. We then divided the future traffic volume on urban freeways by 5-mph speed increments (bins) during peak hours, using data from the Mobility Monitoring Program.[92] For regions without such speed distributions, we estimated the distributions using data from group averages and from similar-sized cities. Based on these, we were then able to estimate the speed distribution for the off-peak, using one distribution for all regions. Using the fuel efficiency/speed curves in the Transportation Energy Data Book, we then estimated fuel use and CO_2 emissions. For 2030, we followed a similar procedure, using 2030 VMT by functional class; speed distributions for each region's VMT were assumed to be the same as in 2005.

For the speed capping policy, we then "capped" speeds at 55 mph for both peak and off-peak periods, moving all traffic at higher speeds to the 55 mph speed bin. In the peak hours, this primarily affects the smaller regions since larger regions have lower peak-hour speeds (but even in large regions a portion of the peak-hour traffic is traveling above 55 mph even though the average is often 25-30 mph). Costs of implementation consist of replacing and maintaining basic speed limit signs (using a sign replacement cost of $1,000 per highway mile over 10 years, and an annual maintenance cost of $50 per highway mile). These costs do not include enforcement, which should not vary much based solely on setting a different speed limit.

For the speed harmonization policy, we capped only peak-hour speeds, but at 50 mph, and moving all peak-hour freeway traffic to 50 mph. The cost of this is installing new control signals above each lane and replacing and maintaining these signs over time. We estimate an installation cost of $250,000 per signal with two signals per mile—one for each direction—over 10 years and an annual maintenance cost of $12,500 per signal. This assumes that the signals have automatic sensors that can adjust speed limits as congestion warrants.

However, these are government costs that do not consider the costs (in lost time) to consumers, which are quite substantial. Consumer costs are often overlooked, since they are often not direct. In this case, the annual cost of a speed cap to highway users (in lost time) is almost $12 billion for a 55 mph speed cap, and over $8 billion for a 50 mph speed cap during peak hours. These estimates are lowball figures since the former total would increase significantly if weekend travel were considered (which it is not, since the FHWA data used is weekday data). The latter would increase significantly as well if lower speed limits were set during the peak period, the peak period were to be extended, or the reduced speed limits were used in selected off-peak hours.

The following tables summarize the results of our analysis. For *speed capping*, implementing a 55 mph speed cap in these 48 regions saves about 5.05 million gallons of fuel daily, which translates into a reduction of about 45,000 tons of CO_2 emissions daily. This is about 3.0% of the baseline forecast of total emissions, 1,510 KT. Using average signage costs, the cost to the government to do this is about $1.5 million per year or about $0.13 per metric ton per year. As noted above, the cost to the government is very low; essentially limited to the cost and maintenance of speed limit signs. The cost to drivers, however, is several orders of magnitude higher at almost $12 billion per year ($1,056 per ton reduced). This latter cost is likely underestimated as we considered only the value of the lost time from the change in speed limits. We did not consider the compounding effects of slowing traffic on already congested highways, as the reduction of throughput following a speed reduction will increase congestion, which will further reduce speeds and increase the cost to system users.

Table 15: CO_2 Reductions from Capping Speed Limits at 55 mph

Item	2005	2030 Current Speed Limits	2030 Max Speed 55 mph	% Change from 2030	Daily Reduction, from 2030	Cost/CO_2 Ton Reduced
Daily VMT, Million	2,732	4,140	4,140	51.5%		
Daily Fuel, Million Gallons	154.8	*168.1	163.0	-3.0%	5.05	
Daily CO_2, Million Tons	1391	*1.510	1.465	-3.0%	0.045	
Annual Cost, Government, $M			$ 1.468			$ 0.13
Annual Cost, Driver, $M			$11,844			$1,056

*Differs slightly from earlier assessments, due to more detailed calculations.

Costs per ton of emissions reduced vary widely by urbanized area, ranging from $0.39 per ton reduced to as low as $0.05. The regions with the highest traffic volumes tend to be more cost effective as the already low cost of signage is spread out over more motorists. This strategy is clearly cheap, at least to government. But the costs to the system users must be considered here, and these costs also vary widely. Drivers in Rochester would collectively pay (in lost time) $856 for each ton of CO_2 reduced from a 55 mph speed cap, while those in Bakersfield would pay $1,466, or 1.7 times more. The other 46 cities fall within these two extremes with an average “time cost” of about $1,056 per ton reduced.

Table 16: Effects of Capping Speed Limits at 55 mph on CO_2 Emissions by Region

Region *(in order by % change)*	2005 Daily CO_2, Tons, K	2030 Current Speed Limits, Daily CO_2, Tons, K	2030 Max Speed 55 mph, Daily CO_2, Tons, K	Reduction vs. Current, Daily CO_2, Tons, K	Percent Change vs. 2030	Cost to Gov't per Ton Reduced, $	Cost to Drivers per Ton Reduced, $
Cape Coral	7.2	9.6	9.5	0.1	-1.0	0.21	1,218
Tampa	31.5	34.8	34.3	0.5	-1.5	0.18	972
Bakersfield	11.8	14.8	14.5	0.2	-1.7	0.10	1,466
Boise City	5.5	6.8	6.7	0.1	-1.7	0.12	1,050
Lancaster, PA	4.1	3.7	3.7	0.1	-1.8	0.31	1,091
Spokane	5.4	5.3	5.2	0.1	-1.9	0.25	1,087
Fort Collins	5.2	6.3	6.1	0.1	-1.9	0.16	1,087
Orlando	21.3	25.7	25.2	0.5	-2.0	0.19	910
Raleigh	10.5	16.4	16.1	0.3	-2.0	0.15	1,203
Baton Rouge	7.3	7.3	7.2	0.2	-2.1	0.23	1,191
McAllen	4.5	5.5	5.4	0.1	-2.1	0.30	954
Chicago	78.7	70.2	68.7	1.5	-2.2	0.19	1,209
Miami	52.6	58.2	57.0	1.3	-2.2	0.16	927
Albuquerque	7.8	9.5	9.3	0.2	-2.2	0.18	1,103
Grand Rapids	10.6	10.0	9.7	0.2	-2.2	0.28	1,005
Philadelphia	52.8	47.1	46.0	1.1	-2.3	0.26	1,122
Knoxville	14.5	14.5	14.2	0.3	-2.3	0.12	1,163
Milwaukee	20.7	17.0	16.6	0.4	-2.4	0.21	1,152
Jacksonville	16.4	19.3	18.8	0.5	-2.4	0.21	1,017
Tulsa	10.7	9.9	9.7	0.2	-2.4	0.38	1,056
Madison	7.3	6.9	6.7	0.2	-2.4	0.19	1,264
Phoenix-Mesa	48.2	76.9	75.0	1.9	-2.5	0.06	1,128
Des Moines	5.0	5.9	5.8	0.1	-2.5	0.20	911
Salem, OR	2.2	2.3	2.2	0.1	-2.5	0.27	1,252
Portland, OR	10.1	9.8	9.5	0.3	-2.6	0.36	1,022
Washington	61.9	59.6	58.0	1.6	-2.7	0.12	1,139
Atlanta	69.7	71.9	70.0	2.0	-2.7	0.11	1,147
Rochester, NY	10.7	8.7	8.4	0.2	-2.7	0.25	856
Dayton	10.2	8.9	8.7	0.2	-2.7	0.28	1,259
Denver-Aurora	28.5	36.3	35.3	1.0	-2.8	0.15	1,037
Ogden-Layton	5.9	6.6	6.4	0.2	-2.8	0.17	1,043
New York-Newark	137.0	134.4	130.3	4.1	-3.0	0.18	1,021
Seattle-Tacoma	32.9	34.9	33.9	1.0	-3.0	0.19	1,058
St. Louis	33.4	29.6	28.7	0.9	-3.0	0.24	1,137
Louisville	16.8	18.0	17.4	0.5	-3.0	0.17	1,135
Albany	11.5	9.2	8.9	0.3	-3.0	0.23	989
Columbia, SC	5.3	5.1	5.0	0.2	-3.0	0.34	963
Richmond-Petersburg	12.4	12.8	12.4	0.4	-3.2	0.29	1,048
Dallas-Fort Worth	79.3	89.5	86.5	3.0	-3.3	0.10	1,048
Minneapolis-St. Paul	28.8	31.0	30.0	1.0	-3.3	0.19	944
Houston	64.4	96.9	93.6	3.3	-3.4	0.07	1,020
Providence-Fall River	10.1	8.3	8.0	0.3	-3.4	0.39	905
Sacramento	27.5	29.6	28.6	1.0	-3.4	0.07	1,049
Austin	15.2	25.3	24.4	0.9	-3.4	0.07	968
Bridgeport-Stamford	10.6	9.3	8.9	0.3	-3.6	0.22	1,209
Los Angeles-Long Beach	161.5	179.6	172.8	6.8	-3.8	0.06	1,018
San Francisco-Oakland	71.2	72.7	69.5	3.2	-4.4	0.05	1,116
San Diego	34.4	37.6	35.7	1.8	-4.8	0.09	913
Totals/Weighted Average	1,391.0	1,509.6	1,464.7	44.9	-3.0	0.13	1,056

Regarding speed harmonization, in the 48 cities reviewed implementing a 50 mph speed cap during peak hours saves about 1.88 million gallons of fuel daily, which translates into a reduction of about 16,700 tons of CO_2 emissions. This is about 1.1% of the baseline forecast of total emissions, 1,510 KT. Using average signage costs, the annual cost to the government to do this is about $733 million, or about $176 per ton. The annual cost to the drivers is 11 times higher at $8.12 billion, or $1,943 per metric ton of emissions reduced.

Table 17: CO_2 Reduction from Setting Speed Limits in Peak Hours at 50 mph

Item	2005	2030 Current Speed Limits	2030 Max Peak-Hour Speed 50 mph	Percent Change from 2030	Daily Reduction, from 2030	Cost/ CO_2 Ton Reduced
Daily VMT, Million	2,732	4,140	4,140	0%		
Daily Fuel, Million gal	154.8	*168.1	166.1	-1.2%	1.883	
Daily CO_2, Million tons	1.391	*1.510	1.493	-1.1%	0.01672	
Annual Cost, Gov't, $M			$ 733			$ 176
Annual Cost, Driver, $M			$8,120			$1,943

*Differs slightly from prior tables due to more detailed calculations.

As in the speed capping concept above, the governmental costs of speed harmonization also vary widely, from over $2,100 per ton reduced in Portland, OR to $45 per ton reduced in Los Angeles. Again, the cities with the larger traffic volumes tended to be more cost effective as the costs for the installation and maintenance of the lane control signals above each lane are spread out over more vehicles. But this is only part of the total cost of speed harmonization; there is also the annual cost to the drivers, which ranges from almost $3,100 per ton reduced in Portland, OR to $1,532 in San Diego. Similar to speed capping, these driver costs are likely understated since we did not consider the multiplicative effects of the reduced traffic throughput on congestion. Still, even with this likely underestimation, the average combined (government and driver) costs to reduce CO_2 emissions are quite substantial: $2,119 per ton reduced. This strategy may appear attractive to those cities whose costs fall below a few hundred dollars per ton reduced, but the driver costs must also be considered. If so, this option loses some of its appeal.

Table 18: Effect of 50 mph Speed Limits on CO_2 Emissions

Region *(in order by % change)*	2005 Daily CO_2, Tons, K	2030 Current Speed Limits, Daily CO_2, Tons, K	2030 Max Peak Hour Speed – 50 mph, Daily CO_2, Tons, K	Reduction vs. Current, Daily CO_2, Tons, K	% Change vs. 2030 Current Limits	Annual Cost to Gov't per Ton Reduced, $	Annual Cost to Drivers per Ton Reduced, $
Portland, OR	10.1	9.8	9.8	0.0	-0.2	2,132	3,090
Cape Coral	7.2	9.6	9.6	0.0	-0.2	597	2,589
Orlando	21.3	25.7	25.7	0.1	-0.3	643	1,999
Raleigh	10.5	16.4	16.4	0.1	-0.3	443	2,556
Bakersfield	11.8	14.8	14.7	0.0	-0.3	256	2,997
Boise City	5.5	6.8	6.8	0.0	-0.3	314	2,147
Tampa	31.5	34.8	34.7	0.1	-0.4	345	1,859
Louisville	16.8	18.0	17.9	0.1	-0.4	690	2,932
Jacksonville	16.4	19.3	19.2	0.1	-0.4	695	2,236
Rochester, NY	10.7	8.7	8.6	0.0	-0.4	853	1,882
Dayton	10.2	8.9	8.9	0.0	-0.4	860	2,765
Albuquerque	7.8	9.5	9.5	0.0	-0.4	537	2,345
Tulsa	10.7	9.9	9.9	0.0	-0.4	1,234	2,244
Grand Rapids	10.6	10.0	9.9	0.0	-0.4	817	2,135

Table 18: Effect of 50 mph Speed Limits on CO_2 Emissions

Region *(in order by % change)*	2005 Daily CO_2, Tons, K	2030 Current Speed Limits, Daily CO_2, Tons, K	2030 Max Peak Hour Speed – 50 mph, Daily CO_2, Tons, K	Reduction vs. Current, Daily CO_2, Tons, K	% Change vs. 2030 Current Limits	Annual Cost to Gov't per Ton Reduced, $	Annual Cost to Drivers per Ton Reduced, $
Baton Rouge	7.3	7.3	7.3	0.0	-0.4	593	2,434
Knoxville	14.5	14.5	14.4	0.1	-0.4	291	2,377
Spokane	5.4	5.3	5.3	0.0	-0.4	621	2,223
McAllen	4.5	5.5	5.5	0.0	-0.4	859	2,110
Lancaster, PA	4.1	3.7	3.7	0.0	-0.4	783	2,229
Salem, OR	2.2	2.3	2.3	0.0	-0.4	784	2,769
Fort Collins	5.2	6.3	6.2	0.0	-0.4	400	2,222
Philadelphia	52.8	47.1	46.8	0.2	-0.5	592	2,396
Milwaukee	20.7	17.0	16.9	0.1	-0.5	499	2,157
Bridgeport-Stamford	10.6	9.3	9.2	0.0	-0.5	740	2,658
Richmond-Petersburg	12.4	12.8	12.7	0.1	-0.5	964	2,303
Albany	11.5	9.2	9.1	0.0	-0.5	651	2,186
Columbia, SC	5.3	5.1	5.1	0.0	-0.5	969	2,130
Des Moines	5.0	5.9	5.9	0.0	-0.5	511	1,863
Madison	7.3	6.9	6.8	0.0	-0.5	483	2,584
Miami	52.6	58.2	57.9	0.4	-0.6	282	1,705
Providence-Fall River	10.1	8.3	8.3	0.1	-0.7	1,014	1,731
Sacramento	27.5	29.6	29.4	0.2	-0.7	168	1,926
Austin	15.2	25.3	25.1	0.2	-0.7	173	1,768
Ogden-Layton	5.9	6.6	6.5	0.0	-0.7	336	1,895
St. Louis	33.4	29.6	29.4	0.2	-0.8	454	2,176
Denver-Aurora	28.5	36.3	36.1	0.3	-0.8	261	1,986
Seattle-Tacoma	32.9	34.9	34.6	0.3	-0.9	300	2,208
Minneapolis-St. Paul	28.8	31.0	30.7	0.3	-0.9	346	1,759
Phoenix-Mesa	48.2	76.9	76.2	0.7	-0.9	92	2,222
Chicago	78.7	70.2	69.5	0.7	-1.0	208	2,224
Atlanta	69.7	71.9	71.2	0.7	-1.0	152	2,104
New York-Newark	137.0	134.4	132.9	1.5	-1.1	245	1,877
Washington	61.9	59.6	59.0	0.7	-1.1	149	2,209
Dallas-Fort Worth	79.3	89.5	88.5	1.0	-1.1	153	2,009
Houston	64.4	96.9	95.8	1.1	-1.2	99	1,953
San Diego	34.4	37.6	36.8	0.8	-2.1	106	1,532
San Francisco-Oakland	71.2	72.7	71.1	1.6	-2.2	51	1,939
L.A.-Long Beach	161.5	179.6	175.1	4.5	-2.5	45	1,755
Totals/ Weighted Avg	1391.0	1,509.6	1,492.8	16.7	-1.1	176	1,943

H. Reductions in Travel

Reductions in travel (meaning solo-driver personal travel) are often cited in regional transportation plans as a transportation goal for the region.[93] And many plans mention generic actions such as telecommuting, carpooling, transit and HOV lanes, particularly in their treatment of congestion management.[94] However, few plans actually propose specific reductions based on such actions. And actions such as restrictions on driving, employee trip reductions, or auto-free zones are rarely suggested.

Employer trip reduction ordinances (TROs) are one means of reducing peak-period VMT that have been tried in a number of states and localities. The National Center for Transit Research (NCTR) recently compiled a list of 40 Trip Reduction Ordinances in 14 states (and one program from Canada).[95] The target is most often some percent reduction in single-occupant-vehicle commuting trips. Some jurisdictions use civil penalties for employers, ranging up from a few hundred dollars, to encourage programs for alternative commuting options. The states with the most active TRO plans are California and Washington. Washington's program reports that the overall percentage of people who drive to work (in the affected participating employers) dropped 5% from 1993 to 2007, due to the program.[96] California's Senate Bill 113 mandated employer trip reduction programs,[97] and South Coast Rule 2202 requires employers with over 250 employees to choose a trip reduction ordinance from a menu of options. The options include:[98]

- Old vehicle scrapping
- Peak commute trip reduction
- Clean on-road vehicles
- Other work-related trip reduction
- Clean off-road mobile equipment
- Vehicle-miles traveled (VMT) reduction programs
- Remote sensing
- Alternative fuel vehicles
- Other mobile source credit programs (Regulation XVI)
- Air quality investment program
- Emission reduction credits from stationary sources (Regulation XIII)

The state's Economic and Technology Advancement Committee (ETAAC) has recently encouraged the continued efforts of TRO policies.[99]

Another approach to traffic reduction is to encourage reductions in travel through the "three Ds:" increased land use density, greater land use diversity and pedestrian-oriented design.[100] For instance, increasing residential density from four to five dwellings per acre to 12 to 15 dwellings per acre would possibly place destinations closer together and raise accessibility, thereby reducing travel.[101] Increasing land use diversity mixes residential neighborhoods and shops within the community, in hopes that residents will choose to leave their cars at home and walk or bike to destinations. Design involves changing the landscape by relocating parking, planting trees along the streets, creating street grid patterns and providing high quality provisions for pedestrians. This creates more rear alleys and more available parking in the rear of buildings, providing a more appealing neighborhood with hopes of bringing people together socially and making transportation a secondary thought. Most of these ideas have been studied only in theory and have not been extensively tested. And where they have been tried in a few regions, primarily in Transit Oriented Development (TOD) plans[102] or neo-traditional neighborhoods, generally only a small local impact on VMT has been observed and even these are problematic since residents may elect to live in such environments rather than change travel patterns.[103]

Another approach is to engage in generic scenario planning, using integrated land-use/traffic-assignment models to estimate how much VMT might be saved by generic but location-specific changes in land use density or land use mix. Researchers have conveniently surveyed the different scenario growth policies of about 50 regions.[104] Studies found that focusing most new development into compact (central area and TOD-like) locations would reduce regional VMT by an average of 2.3% versus the trend forecast, which averages about a 50% increase over 20 years—in other words, a 5% reduction in the VMT growth rate. However, the regions varied widely in their estimates, from a high of +7.2% *increase* in VMT for the Santee-Lynches (Hilton Head, SC) region to a low of about -17% for the Sacramento area. A second, more recent survey adds detail on both the years that policy would be in effect and the type of policy,[105] creating somewhat larger estimates:

- Phoenix: 3% VMT reduction over 20 years.
- San Francisco: 4.6% reduction in VMT by 2020. Most of the growth in this scenario is located in the existing urban cores of the region.
- Atlanta: GRTA, 7% VMT reduction.
- Baltimore: 8.2% VMT reduction. Redevelopment was emphasized, road capacity maintained at current levels and transit capacity moderately expanded.
- Portland OR: 8.8% VMT reduction over 20 years and 17.6% over 40 yrs. Growth would be contained in the urban growth boundary, plus congestion pricing, transit investment and pedestrian improvements.
- Los Angeles: 10% VMT reduction over 25 years. Housing and jobs would be focused in existing centers and corridors.
- Denver: 12.5% VMT reduction in 25 years. Most growth would locate in infill development sites within the central city and existing suburbs.
- Dallas-Fort Worth: 17% VMT reduction compared to current trend. New growth in existing developed areas, which would accommodate one-third of anticipated new households and two-thirds of new jobs.
- Contra Costa County, CA. 17.3% reduction in VMT in 20 yrs. Growth placed in existing urbanized areas and along rail transit routes.
- Atlanta: (EPA): 38% difference in VMT between worst and best growth scenarios.

In another recent exercise, the Pima Association of Governments (Tucson) reviewed the results of a 16-year travel reduction program.[106] More recently, a study found that the imposition of regional road pricing in Austin would have no discernable effect on land use but would result in about 15% less VMT, about the same reduction as a regional growth boundary.[107] Another study discusses urban modeling of energy use in buildings and travel and predicting the resulting greenhouse gases.[108]

It is important to understand that these studies are not observations of travel, but instead are computer models of the impact of an assumed (and quite extreme) land use pattern on VMT, compared with a trend forecast. The whole exercise is model-driven, dependent on the hidden assumptions between travel behavior and land use or travel prices. And the studies typically do not price the cost of undertaking the action or its probability of success; it is quite difficult to estimate the incremental cost of achieving increased density, although some studies have attempted it.

To test the probable impact of VMT reductions on CO_2 emissions, we first assumed that the policies would apply only to cars and light trucks, since there seems to be no support for a reduction in commercial truck traffic. For the regions in our data set, the VMT policy is therefore applied only to car and light truck traffic, about 92-95% of all traffic, both peak and off-peak. The VMT reduction policy necessarily results in a slightly smaller fuel reduction and CO_2 reduction than the stated policy. Regions with a large share of car and light truck traffic should show larger reductions; those with large commercial traffic shares should show less reduction. Building on the forecast of VMT, fuel use and CO_2 emissions for the base case, we then estimate VMT resulting from the policy. For comparative purposes, we prepared three tests:

- A 5% reduction in the future growth rate of car/light truck VMT. This modest policy proposes to slow only the growth rate of car and light truck VMT by 5%. Because it is applied only to growth and not to total VMT, this policy typically results in a cut of about 1–2% in overall VMT growth.
- A 5% reduction in future (2030) car/light truck VMT. This policy assumes that, on average, about a 5% reduction in VMT by cars and light trucks is potentially achievable. It is generally consistent with the middle range of the VMT reduction scenarios discussed by research, but about twice the overall average (2.3%) reduction.
- A 10% reduction in future (2030) car/light truck VMT. We chose this policy because it is near the upper bound of scenario forecasts. Although some MPO scenario forecasts show more change than this, they would require quite radical changes in land use or restrictions/pricing of personal travel. So a 10% reduction in overall car/light truck VMT seems like a quite extreme policy.

The following table summarizes the results. If the growth rate of car/light truck VMT is cut 5% (with new CAFE standards in place, too), the overall reduction in CO_2 would be about 20,000 tons daily, a 1.4% reduction from the baseline forecast. This modest impact is the result of a relatively small change in the growth rate of regional travel, not its actual amount. This policy might be achievable with investments in transit use and other non-intrusive actions, but of course at some cost.

If future car/light truck VMT were cut 5% below its projected level (with new CAFE standards in place too), overall VMT would be cut about 4.7%, fuel use would be cut 4.1%, and CO_2 cut about 4.0%. The total CO_2 reduced would be about 58,000 tons daily, 4.0% of projected 2030 CO_2 emissions.

Table 19: Impact of VMT Reduction on CO_2 Emissions

Item	Base	New CAFEs	5% Cut in VMT Growth Rate		5% Cut in Car/Light Truck VMT		10% Cut in Car/Light Truck VMT	
	2005	2030	2030	% Change vs. 2030	2030	% Change vs. 2030	2030	% Change vs. 2030
Daily VMT, Million	2,732	4,140	4,073	-1.6%	3,946	- 4.7%	3,753	- 9.3%
Daily Fuel, Million Gallons	154.8	161.5	159.3	-1.4%	155.0	-4.1%	148.4	-8.1%
Daily CO_2, Million Tons	1.391	1.452	1.432	-1.4%	1.394	-4.0%	1.336	-8.0%
Daily Reduction in CO_2, M Tons			- 0.020		-0.058		-0.116	

If the future car-light truck VMT were cut 10% (with new CAFE standards in place too), overall VMT would be 9.3%, fuel use 8.1% and CO_2 8.0% below the forecast values. Overall, the result would be a reduction of about 116,000 tons of CO_2 daily, slightly lower than the 2005 levels. So, a 10% VMT reduction policy applied to cars and light trucks might, if successfully implemented along with the new CAFE standards, put future CO_2 levels *below* current levels. However, given the likely severity of actions needed to actually produce such a result, and its cost, it is unlikely.

The following table shows more detail on the "5% VMT Cut" scenario. We used gasoline price as the policy action triggering a reduction in travel, because the use of other actions, such as higher densities, is less well understood (i.e., elasticities are open to question) and considerably less certain with regard to cost. Using gasoline price as the policy action, along with an elasticity of 0.10 and an average price of \$3.50/gallon, a 5% cut in 2030 car/truck VMT would require an overall price of about \$4.92/gallon[109] and would cost consumers in the 48 cities an extra \$227 million/day. This works out to about \$3,923 per ton of CO_2 reduced. If the long-term price elasticity of travel is higher, the resulting gasoline price might be somewhat lower, but travel might also rebound as drivers shift to more fuel-efficient vehicles. The variation in results by region is not large, since most regions are within one to two percentage points of each other in terms of the percent of VMT that is passenger travel.

Table 20: Details of Impact, 5% Cut in Car/Light Truck VMT

	2030 CO_2 for 5% Cut in Car/Light Truck VMT				2030 CO_2 for 5% Cut in Car/Light Truck VMT Growth Rate	
Region *(in order by size)*	2030 CO_2, K Tons	% Change Vs 2030	Est. Price/ Gal to Get 5% Cut	Cost per CO_2 Ton Reduced	CO_2 at Cut of 5% in VMT Growth Rate K Tons	CO_2 Percent Change vs. Null
New York-Newark	124.0	-4.3	\$5.02	\$3,931	128.1	-1.2
Los Angeles-Long Beach	159.4	-4.1	4.95	\$3,923	163.9	-1.4
Chicago	63.1	-3.7	4.84	\$3,952	65.1	-0.6
Philadelphia	44.1	-3.9	4.91	\$3,945	45.5	-0.8
Miami	53.0	-4.0	4.94	\$3,921	54.5	-1.4
San Francisco-Oakland	65.7	-4.1	4.98	\$3,930	67.7	-1.2
Washington	53.7	-4.2	5.00	\$3,937	55.5	-1.0
Dallas-Fort Worth	83.6	-3.8	4.88	\$3,920	85.7	-1.4
Houston	90.6	-3.9	4.90	\$3,894	92.3	-2.1
San Diego	34.9	-4.2	4.99	\$3,919	35.9	-1.5
Seattle-Tacoma	32.0	-4.0	4.92	\$3,926	32.9	-1.3
Atlanta	65.0	-3.9	4.90	\$3,932	66.9	-1.1
Minneapolis-St. Paul	28.6	-4.1	4.96	\$3,922	29.4	-1.4
Phoenix-Mesa	72.1	-3.4	4.74	\$3,900	73.2	-1.9
St. Louis	28.0	-3.8	4.86	\$3,946	28.8	-0.8
Tampa	32.3	-4.2	4.98	\$3,918	33.2	-1.5

Table 20: Details of Impact, 5% Cut in Car/Light Truck VMT

	2030 CO_2 for 5% Cut in Car/Light Truck VMT				2030 CO_2 for 5% Cut in Car/Light Truck VMT Growth Rate	
Region *(in order by size)*	2030 CO_2, K Tons	% Change Vs 2030	Est. Price/ Gal to Get 5% Cut	Cost per CO_2 Ton Reduced	CO_2 at Cut of 5% in VMT Growth Rate K Tons	CO_2 Percent Change vs. Null
Denver-Aurora	33.6	-4.2	5.00	$3,903	34.5	-1.9
Milwaukee	16.2	-3.9	4.89	$3,954	16.7	-0.6
Portland, OR	9.2	-4.1	4.95	$3,932	9.5	-1.1
Providence-Fall River	7.9	-4.4	5.05	$3,950	8.2	-0.7
Sacramento	28.0	-4.1	4.97	$3,919	28.8	-1.4
Orlando	24.1	-4.0	4.91	$3,911	24.6	-1.6
Louisville	17.2	-3.6	4.80	$3,926	17.6	-1.3
Jacksonville	18.2	-4.0	4.91	$3,913	18.6	-1.6
Bridgeport-Stamford	8.7	-4.0	4.94	$3,945	9.0	-0.8
Richmond-Petersburg	12.2	-4.0	4.94	$3,924	12.5	-1.3
Rochester, NY	8.2	-4.4	5.05	$3,954	8.5	-0.6
Dayton	8.5	-3.8	4.86	$3,946	8.8	-0.8
Austin	24.0	-4.2	4.98	$3,880	24.4	-2.4
Albany	8.7	-4.1	4.96	$3,957	9.1	-0.5
Albuquerque	9.1	-3.7	4.82	$3,913	9.3	-1.6
Tulsa	9.4	-4.0	4.93	$3,938	9.7	-1.0
Grand Rapids	9.5	-3.9	4.90	$3,936	9.8	-1.0
Baton Rouge	7.1	-3.5	4.75	$3,934	7.2	-1.1
Columbia, SC	4.9	-3.8	4.86	$3,934	5.0	-1.1
Raleigh	15.5	-3.9	4.89	$3,891	15.8	-2.1
Knoxville	13.8	-3.9	4.91	$3,929	14.2	-1.2
Bakersfield	14.2	-3.5	4.75	$3,914	14.5	-1.6
Des Moines	5.6	-4.1	4.96	$3,910	5.8	-1.7
Spokane	5.1	-3.9	4.88	$3,933	5.2	-1.1
McAllen	5.3	-3.9	4.90	$3,910	5.4	-1.7
Ogden-Layton	6.3	-3.5	4.77	$3,924	6.4	-1.3
Madison	6.5	-3.7	4.83	$3,939	6.7	-1.0
Cape Coral	9.0	-4.0	4.92	$3,902	9.2	-1.9
Lancaster, PA	3.5	-3.9	4.91	$3,941	3.6	-0.9
Boise City	6.4	-4.1	4.97	$3,905	6.6	-1.8
Salem	2.2	-3.8	4.85	$3,927	2.2	-1.3
Fort Collins	5.9	-4.2	5.00	$3,907	6.1	-1.8
Totals/Weighted Avgs.	1394.0	-4.0	$4.92	$3,923	1432.2	-1.4

These costs per ton reduced are quite high relative to other (vehicle technology, signal timing, speed controls) policies. The implications of this policy are that even relatively modest reductions in CO_2 emissions from VMT reductions are likely to be difficult to achieve without quite large increases in gasoline prices, either through taxes (a step that seems unlikely in the U.S.), or market actions. And even if imposed, these price increases would likely have little effect. Therefore, the possibility of using VMT reductions as a way to significantly reduce CO_2 emissions even marginally seems remote.

I. High Occupancy and Toll Lanes

So-called HOV ("high occupancy vehicle") and HOT ("high occupancy toll") lanes are a form of special-purpose freeway lanes designed to reward some travelers either for carpooling or driving a less-polluting vehicle, or for paying for a faster trip. It is a method of placing fees or conferring benefits (usually faster or more reliable travel times) on road users based on the level of demand or on a societal objective.[110] Three variants of the service are: [111]

- HOV (high-occupancy vehicle) lanes, which are reserved for vehicles with two (sometimes three) or more persons, and often other vehicles (buses, electric-vehicle, etc).
- HOT1.0 (high-occupancy toll) lanes, reserved for HOVs *and* other vehicles willing to pay a toll for access.
- HOT2.0 (high-occupancy-toll) express lanes open to all traffic willing to pay the toll, with reduced rates or no toll for some vehicles such as buses.

The first, HOV, designates carpool lanes for use by high occupancy vehicles and selected others, sometimes by selected time or direction. This strategy is intended give carpoolers a time advantage that encourages solo drivers to carpool, thereby increasing road efficiency. They were first implemented in the 1970-80s in Houston, northern Virginia and Santa Monica. However, as carpool rates have declined nationally many regions found that the unused excess capacity ("bare pavement") in HOV lanes was substantial. The realization that many carpools are actually "family-pools"[112] that don't reduce peak-period vehicle use further weakened their justification. Even though these lanes are increasingly coming under review, they are still the dominant style of HOV/T lane.

The second, HOT1.0 lanes, "first generation" HOT lanes, are essentially HOV carpool lanes that sell the excess capacity to solo drivers for a toll. In this model, toll rates are set such that the HOT lane maintains its time advantage but solo drivers are induced to shift from general-purpose lanes, for a price. The toll rate can be varied according to the speed differential between the general-purpose and the tolled lanes. This variant is gaining interest, since it involves little additional expenditure (save for the conversion cost) and increased overall lane use and freeway flow rates.

The third variant, HOT2.0 lanes, extends the idea to provide express toll lanes that may give some discounts for HOV or other vehicles, but in some cases operate as pure express toll lanes (all vehicles pay).[113] Some metro areas are planning entire networks of such lanes, which permit smooth flow between road sections throughout the region. The first HOT 2.0 was implemented on SR 91 in California and the second on I-95 in Miami. Additional HOT 2.0 projects are under construction in northern Virginia, Dallas-Fort Worth and Fort Lauderdale. Among the metro areas with networks of HOT lanes in their long-range plans are Atlanta, Dallas, Houston, San Diego, San Francisco and Seattle.[114]

About 20 U.S. metropolitan areas now have some HOV or HOT1.0 lanes, and about 10 are considering HOT networks (HOT2.0 lanes). The following table summarizes some key features of the HOV or HOT lanes in the 48 regions we reviewed. Of our 48 selected cities, 14 have HOV or HOT lanes now, and two others (Raleigh-Durham and Austin) are planning them. In those regions, the HOV-HOT lanes operate only on freeways, which are only about 2 to 3% of urban mileage but carry about 30 to 50% of urban area traffic. They do not cover the entire freeway system but are generally constricted to about 15–25% of a city's freeways (LA and SF are exceptions, at 55% and 69%, respectively). When operating, they carry typically 20–30% of the total traffic (vehicles) on the freeway. When all these limitations are combined, only two of our regions (LA and SF) currently have more than 15% of total *regional* VMT exposed to HOV or HOT lanes, the others have 5% or less exposed, and somewhat less than that actually use the lanes.

Table 21: Features of Selected Regions HOV and HOT Lanes

Region	2005 Frwy Miles	2008 HOV/T Miles	2008 HOV/T Lane-Miles	% of Flow in HOV Lanes	% of Frwy Miles with HOV/T Lanes	% of Frwy Lane-Miles HOV/T	Congested Speed, mph	Percent of Frwy VMT Congested	% of Regional VMT Exposed to HOV Lanes
Los Angeles	673	369	769	16.8	54.9	13.7	31.4	63	15.3
San Fran	274	190	341	16.8	69.4	17.2	35.7	45	15.8
Washington	330	96	266	33.9	29.1	13.0	36.4	45	4.8
Seattle	321	110	195	15.9	34.3	10.7	39.9	36	5.0
Phoenix	202	73	146	12.8	36.1		40.7	36	4.2
Miami	329	58	116	23.2	17.6	5.7	38.7	27	1.3
New York	1221	66	96	6.0	5.4	1.3	39.6	36	0.7
Atlanta	360	40	72		11.0		37.7	36	
Houston	378	71	71	15.0	18.9	2.9	38.7	36	2.9
Sacramento	117	33	66	20.8	28.2	8.3	40.1	20	2.3
Minneapolis	321	18	65	18.7	5.5		41.0	27	0.6
Dallas-FW	522	29	57	15.0	5.6	1.8	40.4	36	0.9
San Diego	277	15	25	23.6	5.7	1.3	39.0	36	1.1
Denver	259	11	21	15.0	4.3	1.7	39.3	30	0.4
Total		1,179	2,306						

Source: Federal Highway Administration, Features of HOT and HOV Lanes (Existing and Planned) tabulation provided by P. DeCorla-Souza, October 2008.

However, considerable additional mileage has been proposed. Poole and Balaker have proposed large HOT2.0 networks for 19 large regions. This would constitute a tripling of the 2008 mileage (to about 7,597 lane-miles) at a cost of about $98.3 billion. About 20% of the additional mileage suggested by Poole and Balaker would come from conversions, with higher percentages in LA and SF.

The draw for these proposals seems to be a combination of reducing congestion and raising revenue. Atlanta has plans for a conversion project that would change HOV lanes to HOT lanes for $110 million and is being supported by a federal government grant, and also has a Managed Lanes System Plan adopted in Dec. 2009, which would add 900 lane-miles total at a cost of $16.2 billion, and has recently converted some of the I-85 HOV lanes to HOT lanes.[115] The Miami/Fort Lauderdale area is underway on a $1.8 billion highway expansion project that will add an additional three reversible toll lanes to I-595.[116] Florida Department of Transportation hopes to reduce congestion by pricing the toll lanes so that the amount of travelers using the lanes will keep free-flow conditions. A Dallas region study found that if existing multi-occupant vehicles were asked to pay a toll, their shares would not drop significantly, but revenues would rise about 10%.[117] These are just three examples; in our review of 22 large regions, we found that 19 had major HOV/T initiatives but they are rarely proposed in regions under a million persons.[118]

The maximum potential impact of freeway-wide road pricing has been recently studied for six cities (Atlanta, Chicago, Houston, Los Angeles, New York and Washington, D.C).[119] In the tests, all congested sections of the freeway network were tolled for a total of six to eight hours a day during peak drive times, using rates of $0.20/mile (NY, $0.40/mile), with gasoline prices per gallon ranging between $1.70 and $2.10. Results estimated a 4 to 6% reduction in VMT *on the systems tolled*, and an overall regional VMT reduction between 1.5% and 3.0%. The study by Poole and Balaker assumed similar operation but full flow rates (LOS E) in peak hours and LOS C in off-peak hours and reverse direction, and arrived at a similar potential. A study by HDR tested the application of several operational alternatives for the full freeway systems of LA, Chicago and DC, and estimated a -1.0 to -3.2% decline in regional CO_2 for an aggressive (full pricing on all freeways) scenario.[120] In a separate study, FHWA analyzed four regions (LA, Chicago, DC and Seattle), finding -1.1 to -1.5% reduction in regional VMT for three of the four regions.[121] Both studies assumed limited construction costs, since the whole freeway system (including use of shoulders) was assumed to be converted to HOT lanes, an unlikely possibility. These results can be taken as a likely maximum, since the whole freeway system was tested and costs were minimized, and three of these regions have the current highest HOV-lane use.

Short of the politically unrealistic model of pricing all freeway lanes, a quite small percentage of traffic in a given region may actually be exposed to HOV or HOT lanes, and of that a smaller portion of drivers may actually use them. For the individual driver, the value of the time advantage offered by these lanes (their speed is higher than the general-purpose lanes) must of course more than offset the toll, but that is usually the case only in the larger regions where congestion is more severe. If only a portion of a freeway system is outfitted with such lanes, if congestion is limited in duration and if tolls are applied, then the potential for HOT lane use may be quite limited. Federal law presently prohibits tolling most Interstates except in limited circumstances, and the politics of tolling is not conducive to widespread application.

The goal of our analysis is not to evaluate individual toll proposals, of which there are many, but instead to estimate the probable impact on CO_2 emissions for the HOV/T lanes built so far, and then to determine the effect on CO_2 emissions if HOV/T lanes, operating in various ways, were significantly expanded. HOT2.0 lanes typically do not induce modal shifts but instead result in faster travel for some solo drivers. Therefore the reduction on CO_2 use is caused primarily by speed changes, not by diversion to another mode. To estimate this impact, therefore, we use a "squeeze out" method to determine the portion of the regional travel that could potentially use HOV/T lanes. We first forecast each region's VMT by functional class, yielding a VMT forecast for Interstate/freeway traffic. This traffic is then split into vehicle types. The portion of traffic that could potentially use the HOV/T lanes (VMT exposed) is calculated as:

VMT exposed = (2030 Interstate/Freeway Car-Light Truck VMT)
X (% of Interstate/Freeway system with HOV/T Lanes)
X (Percent of this VMT that is congested)

We estimate the "2030% of freeways with HOV/T lanes" by taking current mileage of HOV/T (from FHWA data) and adding 100 centerline miles for major cities, 50 for medium-sized cities, down to just three to five miles of HOV lane for small cities.[122] This approximately doubles existing HOV/T mileage, but does not cover the entire freeway system. Although this approach yields a somewhat smaller estimate of total mileage, about one-third less than that estimated by Poole and Balaker, we believe it is a reasonable estimate of the mileage that could actually be put in operation over 20 years. With state funding difficulties in 2009–2010, some HOT/V projects are also being delayed.

The "percent VMT congested" (Table 23) is the peak hour portion (about 9% in larger regions, 11 percent in small ones times the number of hours daily that are congested (ranging from seven hours for very large cities down to two hours for small ones).

The "percent of VMT in the HOV/T lanes" comes not from diversion or mode split models, but rather from FHWA data that show generally 20–30% of the peak traffic is in HOV/T lanes, where they now exist.[123] For the future, we assumed 25–30% for larger cities, 20% for smaller ones. This is intended to account for some "pricing diversion" to the lanes and some mode shifting (a smaller amount) from solo to carpool driving. We think 25% is probably a high estimate for most freeways. This estimate is also lower than assumed by Poole and Balaker, who assumed that 30–50% of the traffic in the HOT2.0 network would actually use the faster lanes.

The resulting percent of the regional VMT exposed to HOV/T lanes (Table 23) is smaller than one might think: about 18-19% in Los Angeles and San Francisco; 7–10% in Houston, Phoenix, San Diego, Washington DC and Seattle, and less than 4% in other regions. This is because most of our regions have only 25–35% of their traffic in the peak hours, and the freeway system is likely to have only 30–60% of its lanes outfitted for HOV/T use. The big surprise is New York-Newark, at 1.3%, but it has only limited HOV/T mileage today.

To determine the fuel and CO_2 savings in the HOV/T lanes, estimates of speed are required. The HOV/T lane is assumed to flow at the common urban freeway speed limit, 55 mph. The congested speed on the parallel general-purpose (unpriced) lanes is estimated from the region's future congestion level, as

$$S = 55 \text{ mph/TTI}$$

where TTI is the estimated 2030 congestion index for the city. The estimated congested speeds are in the range of 30–35 mph, and are slower for more congested cities. For each group of traffic (VMT in the HOT/V lanes, other car-light truck VMT and commercial vehicle VMT), fuel use and CO_2 emissions are then determined from fuel efficiency-speed curves and CO_2 conversion rates.

This method is based largely on data from current experiences regarding HOV/T lane use (which is mostly HOV), summarized in the above table. It assumes no major shifting from solo driving to carpooling (which seems reasonable), and no induced VMT from the higher speed in the HOV/T lane. However, it does assume a significant increase in HOV/T mileage (about 1,681 more centerline-miles), and current (not higher) usage rates for HOV/T lanes as a percentage of freeway traffic. This latter estimate seems low, since there might be some additional use from toll-paying solo drivers).

The following tables show the results. *Doubling the HOV/T lane-miles in these 48 regions results in a daily reduction of about 9,250 tons of CO_2, about a 0.64% reduction versus the 2030 baseline* *forecast*. The current reduction from HOV/T lanes is about 3,440 tons of CO_2 daily, about 0.25% of current CO_2 values, so this is about three times that.

Table 22: Impacts of Doubling HOV/T Lanes on CO_2 Emissions

		CAFE Increases	CAFE Increases + Congestion Pricing				
Item	2005	2030	2030	Emission Reduction	% Reduction vs. 2030	Annual Lane Const Cost, $ B	Cost per Ton of CO_2 Reduced
Daily VMT, Million	2,731.6	4,139.2	4,139.2				
Daily Fuel, Million Gal	154.8	161.5	160.5	1.05	-0.65%		
Daily CO_2, Million Tons	1.391	1.452	1.443	0.00925	-0.64%	$ 5.695	$ 2,462

To estimate costs, we assumed that two additional lanes for that portion were outfitted for HOV-T use. While the FHWA and HDR studies noted above assume less additional construction costs, under the assumption that most of the mileage can be converted at very low cost per lane mile, we believe this is unrealistic given the politics of tolling. Indeed, most regions have *added* new lanes to create HOV/T capacity, at considerable cost. Costs for lane construction are drawn from recent estimates of per-mile lane construction costs developed by FHWA for use in financial modeling,[124] which may be high since some regions will convert existing HOV lanes to HOT lanes. They range from about $50 million per lane-mile for major work in large, dense regions, down to about $5 million per lane-mile for smaller regions. Using these costs for the additional lane-miles needed in each region, the overall cost is about $5.695 billion annually, or about $113.9 billion over 20 years. This works out to about $2,462 per ton of CO_2 reduced. Of course there are other reasons why HOT/V lanes might be a good idea in specific regions, such as relieving congestion, and a considerable portion of the cost might be recouped through tolls if the lanes were priced.

Details on this action for individual regions are shown in Table 23. The overall aggregate reductions in the table above are primarily from the larger regions, which have, or are likely to have, a significant share of the freeway system outfitted for HOV/T use. These are Los Angeles and San Francisco, both with more than 2% reduction; Washington, Seattle and San Diego with about 1% reduction; and Houston, Phoenix and Atlanta with 0.5% to 0.9% reduction. All other regions are likely to have less than 0.5% reduction potential. On a cost-effectiveness basis, the regions with the most cost-effective actions are those with a large share of traffic likely to use the facilities: LA, SF, Houston, Phoenix and Sacramento have costs under $2,000/ton reduced, but only two of these (LA and SF) are under $1,000/ton reduced. In mid-sized and smaller regions, the cost of the lanes seems unlikely to result in significant CO_2 reduction and is also cost-ineffective, with costs per ton of CO_2 reduced in the $4,000–$30,000 range.

Table 23: Details of Impacts, HOV and HOT Lanes

Region *(in order by percent reduced)*	HOV/T Center-line Miles to Be Added	2030 Percent Frwys With HOV/T Lanes	2030 Percent VMT Exposed	2030 Daily CO_2 K Tons	Percent CO_2 Reduction vs. Null	Cost, in B$ 2006	20-year $ Cost per Ton CO_2 Reduced
Los Angeles	100	69.8	19.7	162.5	-2.20	10.00	$548
San Francisco-Oakland	30	80.4	18.5	67.1	-2.07	3.00	$422
Washington	100	59.4	9.9	55.4	-1.14	8.00	$2,508
San Diego	100	41.8	8.0	36.1	-0.91	6.00	$3,612
Seattle-Tacoma	100	65.4	9.7	33.1	-0.90	6.00	$3,977
Houston	100	45.3	7.2	93.6	-0.66	6.00	$1,924

Table 23: Details of Impacts, HOV and HOT Lanes

Region *(in order by percent reduced)*	HOV/T Center-line Miles to Be Added	2030 Percent Frwys With HOV/T Lanes	2030 Percent VMT Exposed	2030 Daily CO_2 K Tons	Percent CO_2 Reduction vs. Null	Cost, in B$ 2006	20-year $ Cost per Ton CO_2 Reduced
Phoenix-Mesa	50	60.9	7.4	74.2	-0.62	3.00	$1,305
Atlanta	100	38.9	4.7	67.3	-0.51	6.00	$3,482
Miami	100	48.0	3.6	55.1	-0.41	10.00	$8,899
Minneapolis-St. Paul	100	36.7	4.2	29.7	-0.41	6.00	$9,903
Sacramento	25	49.6	4.1	29.1	-0.40	1.00	$1,707
Dallas-Fort Worth	100	24.7	3.9	86.6	-0.35	6.00	$3,903
Chicago	100	20.6	2.6	65.3	-0.27	10.00	$11,287
Denver-Aurora	50	23.6	2.5	35.0	-0.24	2.50	$5,938
Ogden-Layton	20	38.5	2.9	6.5	-0.17	0.60	$10,861
Philadelphia	100	21.4	1.7	45.9	-0.16	10.00	$26,928
New York-Newark	50	9.5	1.3	129.4	-0.13	5.00	$6,123
Tampa-St. Petersburg	50	31.3	1.6	33.7	-0.12	2.00	$9,685
Portland, OR	25	16.6	1.2	9.6	-0.11	1.50	$27,713
St. Louis	50	14.2	1.4	29.0	-0.10	3.00	$19,843
Providence-Fall River	25	13.7	1.1	8.3	-0.07	1.00	$32,617
Bridgeport-Stamford	10	8.2	0.8	9.1	-0.07	0.40	$12,295
Austin	10	9.8	0.8	25.0	-0.07	0.40	$4,906
Milwaukee	25	17.7	1.0	16.8	-0.06	1.00	$19,385
Louisville	15	10.0	0.8	17.8	-0.06	0.60	$11,284
Albuquerque	10	15.6	1.0	9.4	-0.06	0.30	$11,175
Albany	10	9.6	0.8	9.1	-0.05	0.30	$12,903
Orlando	15	9.0	0.5	25.0	-0.05	0.60	$10,410
Rochester, NY	10	10.0	0.7	8.5	-0.05	0.40	$20,205
Raleigh	10	11.9	0.7	16.1	-0.04	0.30	$9,095
Dayton	10	8.9	0.7	8.8	-0.04	0.40	$22,980
Jacksonville	15	9.5	0.6	18.9	-0.04	0.60	$17,539
Bakersfield	5	11.9	0.6	14.7	-0.03	0.15	$5,972
Knoxville	5	7.9	0.5	14.3	-0.03	0.15	$7,279
Baton Rouge	5	8.3	0.5	7.3	-0.03	0.15	$15,213
Des Moines	3	6.0	0.4	5.9	-0.03	0.09	$11,592
Richmond-Petersburg	10	5.2	0.4	12.7	-0.03	0.40	$24,014
Tulsa	10	6.6	0.4	9.8	-0.03	0.30	$24,870
Boise City	2	8.3	0.4	6.7	-0.02	0.06	$7,461
Spokane	3	7.3	0.4	5.3	-0.02	0.09	$15,053
Grand Rapids	5	5.0	0.3	9.9	-0.02	0.15	$15,450
Lancaster, PA	2	5.7	0.3	3.7	-0.02	0.06	$17,839
Columbia, SC	5	5.7	0.5	5.1	-0.02	0.15	$38,796
Madison	2	3.9	0.3	6.8	-0.02	0.06	$11,475
Salem	1	3.7	0.2	2.3	-0.02	0.03	$17,805
McAllen	2	3.4	0.2	5.5	-0.01	0.06	$16,623
Cape Coral	2	6.3	0.2	9.4	-0.01	0.06	$12,686
Fort Collins	1	3.1	0.2	6.2	-0.01	0.03	$9,541
Total/Weighted Avg	1,678		6.1	1,442.6	-0.64	113.9	$2,462

In summary, the potential for modest HOV/T lanes to reduce significant amounts of CO_2 seems limited to those regions with both significant freeway congestion and a strong history of HOV/T lane use. This analysis does not consider network effects that might increase use of HOT lanes on larger regional networks, as suggested by Poole and Balaker, but other studies' results are similar.[125] Absent pervasive freeway congestion, it is not likely that the time savings from HOV/T lanes will be large since there is little difference in speeds, and hence little reduction in CO_2. In the larger regions with an HOT/V system in place or possible, the policy might work reasonably well and might be cost-effective. Of course, there are other good reasons to introduce HOV/T lanes (efficient lane use, time savings, operating costs, some fuel savings, congestion reduction, revenues, etc.), but for most regions CO_2 reduction does not appear to be one of them. Our assessment suggests that for regions less than about three million persons or those without a history of HOV/T use and particularly for the smaller regions, HOT/V lanes may not yield significant reductions in CO_2, even though they might play a significant part in congestion reduction.

We end this section by discussing briefly another approach to congestion pricing, the so-called "congestion cordon." This policy restricts access or charges a fee to enter a specific area such as a downtown. These have an ancient history: planners often reference Julius Caesar's edict to restrict daytime wagon and chariot traffic within the walls of Rome.[126] The best known modern examples are the cordon pricing efforts in London and vehicle use/purchase/pricing restrictions in Singapore. London has recently implemented a cordon area pricing strategy in its downtown district, resulting in a 10–11% decrease in traffic volume inside the cordon, a 30% reduction in delays and about a 1–2% overall drop in VMT for the region.[127] Singapore has had electronic road pricing since 1998 and congestion pricing since 1975.[128] No actions even remotely approaching these have been implemented in the U.S., although two have been proposed. In 2007 New York City proposed a vehicle charging plan, $8 to enter lower Manhattan, but the plan was defeated by the legislature.[129] San Francisco is studying a potential cordon zone for the downtown area. The proposal would charge $3 to enter the downtown area during weekdays, with goals of encouraging transit use, already 40%, and alternatives to driving.[130] The intent is to reduce congestion and greenhouse gases and increase traffic speeds. [131] However, the plan appears to lack strong political support.

J. Transit and Carpooling

Transit and carpool commuting (ridesharing and vanpooling) are two policies that are frequently mentioned as part of air quality improvement and transportation plans, but as a share of travel they are flat or declining in most regions. Research notes the recent trends.[132] Transit shares are flat (up some in 2008); carpooling continues to decline and is dominated by family-member riders. Walking shares also are declining. On the other hand, drive-alone and work-at-home shares are rising. Although there has been some increase in ridership recently, overall transit shares are stable.

Preliminary results from the National Household Travel Survey also support these trends: to-work auto occupancy is constant at 1.15 (implying no significant shift to other modes), and even non-work auto occupancy is rising (implying declines in non-work alternate mode shares).[133]

Table 24: Commuting Shares by Mode, U.S.

Mode	2000 Census	2006-08 American Community Survey	Trend
Drive Alone	75.7	75.9	Up, flattening
Carpool	12.2	10.6	Down slowly
Transit (including taxi)	4.6	4.9	Flat, recently up
Walk	2.9	2.8	Down slowly
Work at Home	3.3	4.1	Up

Source: Alan Pisarski, Commuting in America III, Transportation Research Board, 2005, Table ES-3, and Census Bureau, American Community Survey, 2006-08.

In spite of these trends in personal travel, most of the 48 regions we reviewed were planning to spend significant portions of their transportation budgets expanding their transit systems, even in smaller cities. However, virtually all were predicting little or no major shift in transit shares, instead asserting that transit shares would be essentially the same in the future as at present.[134] Therefore, even with major new investments, transit shares may not significantly rise in most regions, although transit *ridership* may increase.

Citizens often wonder why U.S. regions have much lower transit shares than European regions. But a recent survey of five European regions (Dublin, Munich, Freiburg, Milan and Bilbao) found only slightly higher regional densities there than in the U.S., and also rapid suburbanization: “Suburban/exurban growth was overwhelming the five cities, similar to experiences in the United States in the early 1980s and the 1990s.”[135] Although transit shares are higher, particularly for work, car ownership is increasing rapidly. These regions were also found to be struggling to hold transit shares at current levels.

But even if transit or carpool commuting shares could be significantly increased, the effect of such policies would not be as large as is often thought. These modal shift policies would largely affect travel to work and back, which is (optimistically) about 27 to 35% of all weekday travel,[136] and is declining as a share of travel. And transit commuting shares are quite low in most regions. Only a few cities have commuting shares greater than 10% transit, and most regions have only 1 to 3% of commuters using transit (see Table 24). Transit shares for non-work travel are even lower. So, even if to-work transit shares doubled, the impact on overall travel might be quite small.

In most regions carpooling shares are about three to 10 times higher than transit shares, about 8 to 12% of commuters in most regions, but these numbers are also declining as auto ownership increases and more commuters use their own vehicles rather than share rides. And almost 80% of to-work carpools are not composed of unrelated coworkers; instead, they are “family carpools” in which family members ride together. Providing HOV lanes essentially gives them an unneeded subsidy. And when diversion from solo driver to transit or to carpooling does occur, not all diversion results in less VMT because some vehicles are used by other household members, or the increase comes from other transit modes or from walking.[137] And of course, truck traffic would not be affected.

To undertake our assessment, we began with prior forecasts of the impact of the new CAFE standards, described above. Two policies were tested:

- **Increase transit commuting shares by 50%.** This is a very substantial increase indeed. In the New York-Newark region, with a 30% transit work share at present, this would mean increasing the transit work share to 45%. For most other cities, however, it means a one to three percentage-point increase in the transit share. This might be possible, but only through very large expansions of transit service, major gasoline price increases, major increases in parking fees, or the elimination of transit fares.
- **Increase carpool commuting shares by 25%,** also an extreme action. For the New York-Newark region, the current carpool share is 8%, so this would increase it to 10%. Although this is a more modest policy than the transit policy, it affects a much larger commuting pool in most regions. On the other hand, it is difficult to imagine any policy that could get this to actually happen, short of gasoline rationing or supply cuts or very high parking fees. So this seems like a very unlikely assumption.

We also optimistically assume that all of the shift would come from solo-driver commuting. For the New York-Newark region, this would mean reducing the drive-alone share 17.2 percentage points, from 50.4% to 33.2%. And for Austin, the change in drive-alone share would be from 76.5% down to 71.9%, a decline of 4.6 percentage points. But since work travel (to work and back) is (optimistically) about 35% of all private-car VMT, only about 35% of private-vehicle VMT would be affected; other non-work private car use would not be affected, nor would weekend travel. And of course single-axle truck and combo truck VMT would not be affected. Therefore, the reduction in VMT cars and light trucks would be the reduction in the drive-alone share *times 0.35*. For New York, this is -6.0%, for Austin -0.61%. This means that even a fairly large (e.g. 50%) increase in transit commuting share and a 25% increase in carpooling share would together have a relatively small effect on VMT in most regions.

Overall results are shown in the following table. A 50% increase in the transit commuting share would reduce overall CO_2 emissions in these 48 regions by about 16,000 tons of CO_2 daily, or about 1.09%, compared with the 2030 null forecast. A 25% increase in the carpooling to-work share would decrease CO_2 emissions by about 9,000 tons of CO_2 daily, or 0.75%. Together, a combined policy of a 50% increase in transit share and a 25% increase in carpooling share would reduce CO_2 emissions by about 27,000 tons daily, or about 1.82% overall.

To estimate the cost of transit shift policies, we reviewed costs per revenue vehicle mile for transit service in each community.[138] We also reviewed possible pricing actions such as raising gasoline prices[139] or reducing transit fares. Although the most cost-effective action to increase transit shares by 50% would be to offer fare-free service at about $1,398 per ton of CO_2 reduced, we believe that this policy could not be implemented in most regions. Aside from several year-long demonstrations in the 1980s and 1990s,[140] free-fare transit service has not been implemented on any large U.S. transit system, for both cost and policy reasons. Some university-based services are free-fare, but those are controlled environments.[141] Even though they are more costly, service improvements are seen as a more politically viable way to increase ridership. Over the past several decades many regions have tracked the effect of changes in transit fares and services on both ridership and on car use. A 2003 study, *Traveler Response to Transportation System Changes*, reports that travelers' response to scheduling and frequency changes of transit has an average service elasticity of +0.5, while bus routing and coverage increases have an elasticity of +0.6 to +1.0, and service expansions an elasticity +0.7 to +0.8, on average.[142] The VTPI Online TDM Encyclopedia provides a similar finding.[143]

Table 25: CO_2 Emissions Impact of Increasing Commuting Transit Share 50% and Carpool Share 25%

Item	2005	2030 CAFE	+50% Transit Share	Percent Reduction vs. 2030 CAFE	+25% Carpool Share	Percent Reduction vs. 2030 CAFE	Both	Percent Reduction vs. 2030 CAFE
Daily VMT, M	2,732	4,139	4,087	-1.26	4,103	-0.88	4,051	-2.14
Daily Fuel, MG	154.8	161.5	159.8	-1.09	160.3	-0.77	158.5	-1.86
Daily CO_2, MT	1.391	1.452	1.436	-1.09	1.441	-0.75	1.425	-1.82
Daily CO_2 Reduction, KT			0.016		0.009		0.027	
Annual Cost ($B)			$ 16.599		$ 7.550		$ 24.149	
Cost/Ton Reduced			$ 4,257		$ 2,776		$ 1,964	

Transit service elasticity has not changed much over the years. A 1978 study reported on the effects of service expansion in 11 North American cities.[144] Ridership increases ranged from 8.3% in Seattle to 271.3% in Eugene.[145] However, the range in elasticities was less, from a low of 0.41 for Raleigh to a high of 1.34 for Eugene. Overall, the study shows an elasticity average of +0.89.[146] A study conducted in 1991 on transit fare elasticities shows that in large cities (more than one million population), the average elasticity was -0.36 and for smaller cities (less than one million population) it was -0.42.[147]

This information is the best experiential data for estimating the effects of service increases. A more serious problem, that of the impact of very large changes, has not been extensively studied, although *Traveler Response to Transportation System Changes* notes that service changes in large regions (smaller relative changes) tend to have lower elasticity while those in smaller regions (larger relative changes) tend to have higher elasticity. What we do not know is the effect of *large service changes in large regions*, which is the case studied below.

Considering the studies above, we have elected to use a conservative transit service elasticity of 0.60, meaning that a 100% increase in service yields a 60% increase in ridership. For a 50% increase in ridership, therefore, an 83% increase in service would be needed, on average. This is a very large increase indeed, and is likely to be significantly beyond the capabilities of most large transit systems. Using the current (2006) operating cost per vehicle mile for the systems, the following table shows the details of CO_2 reductions and additional costs for expanded service. Overall, about $16.6 billion in additional service (not counting significant capital costs) would be needed, but about one-third of that is in just one region: New York-Newark. But only eight regions (New York-Newark, San Francisco, Washington DC, Chicago, Philadelphia, Bridgeport, Seattle and Portland, OR) would obtain a better than 1% reduction in CO_2 emissions. Other regions typically have a much smaller overall decrease. On a cost-effectiveness basis, the policy averages $4,257 per ton of CO_2 reduced, but this ranges from a low of $472 for Bridgeport, CT (served by rail service to New York-Newark) to a high of $11,899 for Salem, OR.

The above assessment does not consider the CO_2 effects of additional transit service, which can be considerable. If trips are shifted to expanded transit, then some CO_2 would be emitted in providing that service.[148] If included, this effect would reduce the potential CO_2 reduction and raise the cost per ton reduced.

These findings mean that even though the overall reduction in CO_2 can be quite high for some regions, the cost of capturing them is also quite high for most regions. The implication is that CO_2 reduction policies that focus on increasing transit use should be carefully reviewed for likely impact in each region before implementation.

Table 26: Details of Impact for 50% Increase in Transit Work Share

Region (In order of percent change in CO_2)	2005 Public Transit Work Share	2030 PT Work Share	% Change in Regional VMT	2030 CO_2, K Tons/ Day	Reduction vs. 2030 Base	% Change in CO_2	Annual Cost of Increased Service, $M	Cost/ Ton of CO_2 Reduced
New York-Newark	30.6	45.9	-5.4	123.6	6.0	**-4.6**	$5,836	$3,922
San Francisco-Oakland	15.9	23.9	-2.8	67.0	1.6	**-2.3**	$470	$1,188
Washington	15.7	23.6	-2.7	54.7	1.3	**-2.3**	$1,422	$4,383
Chicago	11.9	17.9	-2.1	64.5	1.0	**-1.5**	$1,623	$6,422
Philadelphia	9.7	14.6	-1.7	45.3	0.6	**-1.3**	$1008	$6,557
Bridgeport-Stamford	9.3	14.0	-1.6	9.0	0.1	**-1.3**	$14	$472
Seattle-Tacoma	7.6	11.4	-1.3	33.0	0.4	**-1.1**	$503	$5,720
Portland, OR	7.6	11.4	-1.3	9.5	0.1	**-1.1**	$3,033	$11,655
Los Angeles-Long Beach	5.8	8.7	-1.0	164.8	1.4	**-0.8**	$1,202	$3,499
Minneapolis-St. Paul	4.8	7.2	-0.8	29.6	0.2	**-0.7**	$2,419	$4,717
Denver-Aurora	4.3	6.5	-0.8	34.9	0.2	**-0.6**	$439	$7,923
Austin	3.8	5.7	-0.7	24.9	0.1	**-0.6**	$143	$4,130
Madison	4.9	7.4	-0.9	6.8	0.0	**-0.6**	$39	$3,681
Miami	3.6	5.4	-0.6	55.0	0.3	**-0.5**	$487	$6,924
San Diego	3.1	4.7	-0.5	36.3	0.2	**-0.5**	$92	$2,212
Atlanta	4.0	6.0	-0.7	67.3	0.4	**-0.5**	$433	$4,688
Milwaukee	3.5	5.3	-0.6	16.8	0.1	**-0.5**	$148	$7,380
Houston	3.2	4.8	-0.6	93.8	0.4	**-0.4**	$387	$3,742
St. Louis	2.8	4.2	-0.5	29.0	0.1	**-0.4**	$219	$8,147
Providence-Fall River	2.9	4.4	-0.5	8.2	0.0	**-0.4**	$79	$8,622
Albany	2.9	4.4	-0.5	9.1	0.0	**-0.4**	$49	$5,208
Dallas-Fort Worth	1.9	2.9	-0.3	86.7	0.2	**-0.3**	$432	$7,783
Phoenix-Mesa	2.5	3.8	-0.4	74.4	0.2	**-0.3**	$130	$2,321
Sacramento	2.4	3.6	-0.4	29.1	0.1	**-0.3**	$151	$5,989
Orlando	2.0	3.0	-0.4	25.0	0.1	**-0.3**	$97	$5,626
Louisville	2.3	3.5	-0.4	17.7	0.1	**-0.3**	$51	$3,927
Richmond-Petersburg	2.1	3.2	-0.4	12.7	0.0	**-0.3**	$32	$3,451
Rochester, NY	2.0	3.0	-0.4	8.5	0.0	**-0.3**	$55	$8,516
Bakersfield	2.2	3.3	-0.4	14.7	0.0	**-0.3**	$23	$2,393
Spokane	2.5	3.8	-0.4	5.2	0.0	**-0.3**	$46	$10,522
Ogden-Layton	2.1	3.2	-0.4	6.5	0.0	**-0.3**	$34	$8,116
Salem, OR	2.5	3.8	-0.4	2.3	0.0	**-0.3**	$22	$11,899
Tampa-St. Petersburg	1.4	2.1	-0.2	33.7	0.1	**-0.2**	$52	$3,014
Jacksonville	1.4	2.1	-0.2	18.9	0.0	**-0.2**	$72	$7,825
Dayton	1.8	2.7	-0.3	8.8	0.0	**-0.2**	$52	$9,900
Albuquerque	1.5	2.3	-0.3	9.4	0.0	**-0.2**	$42	$9,272
Grand Rapids	1.1	1.7	-0.2	9.8	0.0	**-0.2**	$29	$8,001

Table 26: Details of Impact for 50% Increase in Transit Work Share

Region (In order of percent change in CO_2)	2005 Public Transit Work Share	2030 PT Work Share	% Change in Regional VMT	2030 CO_2, K Tons/ Day	Reduction vs. 2030 Base	% Change in CO_2	Annual Cost of Increased Service, $M	Cost/ Ton of CO_2 Reduced
Baton Rouge	1.5	2.3	-0.3	7.3	0.0	**-0.2**	$26	$7,882
Columbia, SC	1.8	2.7	-0.3	5.1	0.0	**-0.2**	$9	$2,988
Lancaster, PA	1.5	2.3	-0.3	3.7	0.0	**-0.2**	$15	$7,989
Tulsa	0.8	1.2	-0.1	9.8	0.0	**-0.1**	$16	$5,694
Raleigh	1.0	1.5	-0.2	16.1	0.0	**-0.1**	$11	$2,009
Knoxville	0.7	1.1	-0.1	14.3	0.0	**-0.1**	$14	$4,146
Des Moines	1.0	1.5	-0.2	5.9	0.0	**-0.1**	$14	$6,496
Cape Coral	0.9	1.4	-0.2	9.3	0.0	**-0.1**	$15	$5,168
Boise City	0.6	0.9	-0.1	6.7	0.0	**-0.1**	$6	$4,361
Fort Collins	1.0	1.5	-0.2	6.2	0.0	**-0.1**	$10	$4,288
McAllen	0.2	0.3	0.0	5.5	0.0	**0.0**	$2	$6,279
Totals/Weighted Average	**1.7**	**2.6**		**1436.2**	**15.6**	**-1.1**	**$16,600**	**$2,462**

To estimate the cost of carpooling policies we assumed that significant increases in carpooling could only be achieved by major increases in agency services, such as vanpooling or carpool matching. Therefore, we reviewed data on the cost of vanpool programs, using data from the 2006 National Transit Database.[149] We determined the cost of vanpool operations, per vehicle-mile, for each region.

Overall results are shown in Table 25 and Table 27 below. The overall cost of a 25% increase in carpooling, using typical vanpool operating statistics, is about $7.5 B, or about $2,776 per ton of CO_2 reduced. This statistic might be high since it assumes that all the new carpool trips would be in organized vanpools, whereas some might be informal between family members or workplace colleagues. On the other hand, some regions might have to expand HOV lanes to accommodate more carpools, adding to the cost. Since the percentage of commuters in carpools is not nearly as variable across the regions, the percentage of reduction in CO_2 emissions is also less variable, ranging from about -1.1% to -0.5%. However, the greatest relative reductions are in regions that have relatively large current carpooling/vanpooling shares. And the costs per ton of CO_2 reduced also are more uniform. This suggests that a carpool increase program, possibly focusing on forming carpools at the home end or by language,[150] might be a viable strategy as part of a package of actions for most regions, but that it would not likely lead to a significant CO_2 emissions decrease by itself.

In summary, the analysis suggests that carpooling/vanpooling programs can play a minor but relatively cost-effective part in most regions, and transit increase programs can also play a part in some regions, but neither is likely to provide significant CO_2 reductions except in a few large regions.

Table 27: Details of Impact, 25% Increase in Carpool Share

Region *(in order by Percent Change)*	2005 CP Share	2030 CP Share	% Change in VMT	2030 CO$_2$, K Tons	% Change in CO$_2$	Annual Cost of Service, M$	Average Cost/Ton Reduced
McAllen	15.9	19.9	-1.4	5.4	-1.1	$24	$1,670
Salem, OR	14.9	18.6	-1.3	2.2	-1.0	$35	$6,345
Los Angeles-Long Beach	12.1	15.1	-1.1	164.7	-0.9	$1,196	$3,339
Washington	11.7	14.6	-1.0	55.6	-0.9	$404	$3,339
Houston	12.8	16.0	-1.1	93.4	-0.9	$303	$1,469
Phoenix-Mesa	14.6	18.3	-1.3	74.0	-0.9	$437	$2,672
Sacramento	13.2	16.5	-1.2	29.0	-0.9	$185	$2,672
Bakersfield	14.6	18.3	-1.3	14.6	-0.9	$10	$301
San Francisco-Oakland	11.1	13.9	-1.0	68.0	-0.8	$461	$3,339
Dallas-Fort Worth	12.2	15.3	-1.1	86.2	-0.8	$476	$2,672
San Diego	10.9	13.6	-1.0	36.1	-0.8	$173	$2,371
Seattle-Tacoma	11.6	14.5	-1.0	33.1	-0.8	$173	$2,571
Portland, OR	10.9	13.6	-1.0	9.5	-0.8	$37	$2,004
Austin	10.9	13.6	-1.0	24.8	-0.8	$121	$2,438
Albuquerque	13.1	16.4	-1.1	9.4	-0.8	$33	$1,670
Columbia, SC	12.0	15.0	-1.1	5.0	-0.8	$17	$1,670
Cape Coral	11.4	14.3	-1.0	9.3	-0.8	$69	$3,740
Boise City	10.7	13.4	-0.9	6.7	-0.8	$21	$1,670
Miami	10.5	13.1	-0.9	54.9	-0.7	$274	$2,672
Atlanta	10.4	13.0	-0.9	67.1	-0.7	$244	$2,037
Tampa	9.9	12.4	-0.9	33.5	-0.7	$121	$2,004
Denver-Aurora	9.1	11.4	-0.8	34.9	-0.7	$98	$1,670
Providence-Fall River	9.6	12.0	-0.8	8.2	-0.7	$35	$2,338
Orlando	10.8	13.5	-0.9	24.9	-0.7	$93	$2,004
Jacksonville	10.8	13.5	-0.9	18.8	-0.7	$71	$2,004
Richmond-Petersburg	9.7	12.1	-0.8	12.6	-0.7	$32	$1,503
Tulsa	9.3	11.6	-0.8	9.8	-0.7	$43	$2,672
Grand Rapids	9.6	12.0	-0.8	9.8	-0.7	$58	$3,573
Raleigh	10.2	12.8	-0.9	16.0	-0.7	$56	$2,004
Knoxville	9.5	11.9	-0.8	14.2	-0.7	$39	$1,670
Ogden-Layton	12.1	15.1	-1.1	6.4	-0.7	$19	$1,603
Lancaster, PA	9.7	12.1	-0.8	3.6	-0.7	$10	$1,670
New York-Newark	7.8	9.8	-0.7	128.8	-0.6	$1,241	$6,545
Chicago	9.6	12.0	-0.8	65.1	-0.6	$204	$2,004
Philadelphia	9.3	11.6	-0.8	45.6	-0.6	$147	$2,004
Minneapolis-St. Paul	9.0	11.3	-0.8	29.6	-0.6	$174	$3,640
St. Louis	8.5	10.6	-0.7	28.9	-0.6	$82	$2,004
Milwaukee	8.2	10.3	-0.7	16.7	-0.6	$30	$1,302
Albany	8.4	10.5	-0.7	9.1	-0.6	$32	$2,338
Baton Rouge	9.3	11.6	-0.8	7.3	-0.6	$17	$1,670
Des Moines	8.9	11.1	-0.8	5.8	-0.6	$11	$1,236
Spokane	9.4	11.8	-0.8	5.2	-0.6	$14	$1,670
Madison	8.7	10.9	-0.8	6.8	-0.6	$22	$2,338
Fort Collins	8.8	11.0	-0.8	6.2	-0.6	$16	$1,670
Louisville	8.6	10.8	-0.8	17.7	-0.5	$48	$2,004
Bridgeport-Stamford	7.6	9.5	-0.7	9.1	-0.5	$71	$5,844
Rochester, NY	6.7	8.4	-0.6	8.5	-0.5	$29	$2,672
Dayton	8.0	10.0	-0.7	8.8	-0.5	$31	$2,672
Totals/ Averages	7.5	9.4		1440.9	-0.75	$7,549	$2,776

K. Work at Home and Walk to Work

Policies that encourage working at home via modern telecommunications, sometimes termed "telecommuting," have long been touted as important elements of transportation demand management. They were a central focus of urban transportation planning in the 1970s and 1980s, when regions focused extensively on transportation demand management and trip reduction policies. They have not been given as much attention in recent years; our review of the transportation plans of the 48 regions selected here found no case in which telecommuting was a central element of either the long-range plan or the congestion management plan for the region.

As the previous section noted, modal shares for work and telecommuting vary quite widely. For the 48 regions we reviewed, transit work shares average 4.2%, close to the national average of 4.6%, but without New York-Newark the average is 3.6%. The range of transit shares is from 30.6% to 0.2%. Working at home is a similar average share at 3.5%, but the range is narrower, from about 5.2% to 1.7%. Walking to work is somewhat lower overall at 2.2%, and its range is even tighter, from 5.8 to 0.8. However, modal shares for work-at-home have been rising over time, while walking shares are declining and transit shares are generally flat. A 2005 Reason study on telecommuting trends found that from 1990 to 2000 the number of those who usually worked at home grew by 23%, more than twice the rate of growth of the total labor market, and much more than the rate of growth of transit use.[151] Since 2000, telecommuting has continued to grow in popularity. Roughly 4.5 million Americans telecommute most work days, roughly 20 million telecommute for some period at least once per month, and nearly 45 million telecommute at least once per year.

Table 28: Commuting Modal Shares for 48 Regions, 2005

	Transit	Work at Home	Walk to Work
Highest	30.6 New York-Newark 15.9 San Fran 15.7 DC 11.9 Chicago	5.9 Ft. Collins 5.2 Spokane 5.1 San Fran 5.1 Boise	5.8 New York-Newark 5.7 Madison 4.5 San Fran
48 City Average	4.2	3.5	2.2
Lowest	0.2 McAllen 0.6 Boise 0.7 Knoxville	1.7 Dayton 1.7 Baton Rouge 2.0 Columbia	0.8 Cape Coral 1.1 Atlanta 1.1 Bakersfield
U.S. Average (2004 ACS)	4.6	3.8	2.4

These findings are largely consistent with other research showing that overall, 52% of the work-at-home workforce lives in the suburbs, and that the number of workers-at-home has grown by 40% from 1980 to 2000.[152] Women comprise approximately 60% of the work-at-home workforce under the age of 45.[153] On the other hand, the walk-to-work workforce has steadily been on the decline for the past 20 years. There are fewer than 3.8 million persons who walk to work, down from 5.4 million in 1980,[154] in spite of transit-oriented development and neo-traditional initiatives. Although many planners think that walk-to-work and walking non-work travel can be potentially large shares of travel, the recent Brookings study charting the flight of jobs to suburbs since 2000 portends continuing decline.[155]

Initially, the potential for work-at-home shares (telecommuting) was thought to be quite high. Most of the initial research was conducted in the 1980s and 1990s, before, we should mention, the full blossoming of the Internet. A 1996 study for the state of California regarding the potential for telecommuting found that telecommuting caused a 27% reduction in the number of personal vehicle trips, and a 77% decrease in VMT for those who telecommute.[156] This translated to telecommuters emitting 48% less total organic gases. However, the study covered only participating agencies and government workers. Another study on the costs and benefits of telecommuting found that the critical cost factors were start-up training and continued support, but that the benefits were primarily in less personal travel and more employee freedom (both employee benefits) rather than employer benefits.[157] Employers also gained in recruiting and retaining workers, but sacrificed administrative control, employee interaction and security. An extensive USDOT study looking at national impact estimated that reduction could reach 17 to 35 billion VMT, about 1 to 2% of U.S. VMT and about 2 to 4% of urban weekday travel, by 2002.[158] We examined four major studies in this report—two independent, one by the Department of Transportation and one by the Department of Energy. These studies, reflecting the typical optimism of telecommuting prevalent at that time, estimated that as much as 12% of the labor force might be able to at least partially telecommute.

Telecommuting, as a percentage of the workforce, rose steadily from 1988 to 1996, but then the increase trailed off.[159] Using average figures for employer and worker benefits and costs, researchers estimated a benefit/cost ratio of 2.24, indicating that the benefits of telecommuting are twice the costs, or about a net benefit to employees of $122/telecommuter/year. They separate effects that contribute to the benefit into miscellaneous (40%), travel time (29%), fuel savings (16%), and insurance/maintenance savings (15%). The primary costs are energy costs (more use of lights, heat/air conditioning), which they estimate to be $98/year (total telecommuter benefits are $220/year).[160] For employers, they estimate a benefit/cost ratio of only 0.52. Employer losses are three times greater than telecommuter benefits, costing an employer $420/telecommuter/year. Since productivity is the primary possible employer benefit, the employer costs (hardware/software equipment, telecommunications costs) can easily outweigh the benefits. The study also notes that the public sector has no benefit for telecommuters (which may not be entirely true), and that the public accrues a $1.3 billion loss in fuel tax revenues over one year for all telecommuters, which affects highway revenues. So, the study concludes that telecommuting is not beneficial, except perhaps to the telecommuter. However, clearly other benefits (employee satisfaction, family life and reduced congestion) do benefit society indirectly.

The interest in telecommuting seems to have faded recently as both a transportation policy alternative and an employer option, and probably at the government level too. This is ironic since recent Census data show telecommuting continuing to rise, and larger than transit commuting in modal share even in large cities. Perhaps most surprisingly, of the 48 regions we reviewed for this study, only a handful even mentioned telecommuting as a strategy for congestion management, and none gave it a major part. Part of this change undoubtedly came from the realization that many elements of on-site working—office culture, working relationships, physical activity, face-to-face interaction with customers, management and administration, etc.—cannot be easily carried on long-distance. In recent years, outsourcing has probably absorbed many of the opportunities that might have gone to computer-based telecommunicating in the 90s. But at the same time, the Internet has certainly changed the nature of work and has encouraged more work-at-home employment. Ironically, the 2005 Annual Housing Survey shows that work-at-home commuting in most regions increased more rapidly than transit use and in smaller regions where work-at-home employment is often two to four times as large as transit commuting.[161] So, working at home is growing as a share of commuting, but not necessarily in the formal, structured way that telecommuting would have required. But even that is not a complete reduction of fuel, CO_2, or even congestion, since some studies find that vehicles left at home are often driven locally or by others.

To evaluate these policies, we studied 50% increases in work-at-home and walk-to-work commuting shares. These are likely to be at the upper end of future shifts in commuting behavior, since very few regions or company programs have experienced increases this large. As noted below, a few regions in our database currently have greater than 5% walk-to-work or 5% work-at-home shares, but most are in the range of 2 to 4%. Work travel (to work and back) is about 35% of daily VMT, and much less (about 10%) of weekend travel.[162] And of course, truck traffic would not be affected. These factors reduce the likely impact of policies even further.

To undertake this evaluation, we began with the national new CAFE standards. Using this as a baseline forecast, we then evaluated two additional policies that increase walk-to-work and work-at-home shares very substantially:

- **Increase walk-to-work shares by 50%.** For instance, if in New York-Newark the current walk-to-work share is 5.8%, this would increase it to 8.7%. This is a quite high walk share, which would probably require significant changes in land use. So this seems like a very high assumption. Given the wide range in costs of development and the uncertainty about the cost of this policy, we have elected not to estimate a cost or cost-effectiveness. However, it seems clear that the cost, in terms of raising urban residential densities, would be very substantial.
- **Increase work-at-home shares by 50%.** In New York-Newark, with a 3.4% work at home share at present, this means increasing it to 5.1%. For most other cities, it means a 1 to 1.5% increase in the work-at-home share. This might be possible, perhaps through increasing communication and computer technology, perhaps gasoline rationing/supply cuts, or possibly major increases in parking fees. However, this policy is not cost-free, since employers would have to provide communications services, and perhaps other costs, to permit widespread telecommuting. We estimated the cost for this policy by assuming average annual implementation and operational costs of between $2,000 and $5,000 per additional telecommuting worker, the higher costs being applicable in larger cities. We obtained these figures by increasing the estimates of direct (employer or government) costs per telecommuter made in the 1990s to 2007.

In each case we assumed (optimistically) that all the increase in walking or working at home would come from the "drive-alone" mode. We also (optimistically) assumed no subsequent loss of emission reduction from incremental use of cars left home.[163] For New York-Newark this means reducing the drive alone share 4.6 percentage points, from 50.4% to 45.8%. For Austin, the change in drive-alone share is -3.2%, from 76.5% down to 73.3%. The resulting VMT reduction for cars and light trucks is the reduction in drive-alone share, *times 0.35*, since work travel is about 35% of daily personal VMT.

Results of the analysis are summarized in the following table. A 50% increase in walk-to-work shares would reduce about 5,000 tons of CO_2 daily, or about -0.35% reduction in 2030 CO_2 emissions, compared with the null forecast. On the other hand, a 50% increase in work-at-home share would reduce CO_2 emissions by about one-third more, 8,000 tons of CO_2 daily, about -0.52%. This is due largely to the higher walk-to-work shares in most communities, compared with working at home. This means that even a large (e.g, 50%) increase in walk-to-work and work-at-home shares would have only a marginal effect on reducing travel in most regions.

Table 29: Summary for Increasing Walk-to-Work and Work-at-Home Commuting Shares

			Walk to Work		Work at Home	
Item	2005	2030 CAFE	2030 +50% Walk to Work	% Change vs. Current Travel	2030 +50% WAH	% Change vs. Current Travel
Daily VMT, Million	2,731.6	4,139.2	4,122.4	-0.41%	4,114.1	-0.61
Daily Fuel, Million Gallons	154.8	161.5	161.0	-0.35%	160.7	-0.53
Daily CO$_2$, Million Tons	1.391	1.452	1.447	-0.35%	1.444	-0.52
Reduction in CO$_2$, KT/D				- 0.005%	-0.008	
Annual Cost, $Billion				Not estimated	$ 6.584	
Cost per Ton Reduced				Not estimated	$ 3,497	

The following table shows more details for the walk-to-work policy. The greatest relative emissions reductions, about 1%, are in dense regions and university towns that have significant walking shares already and could likely increase them the most. However, for most regions, the percentage change in regional VMT caused by a 50% increase in walk-to-work shares is significantly less than 1%.

Table 30: CO$_2$ Impact of Increasing Walk-to-Work Shares by 50%

Region *(in order by Percent Reduction in CO$_2$)*	2005 WTW Share	2030 WTW Share	Percent Change in VMT	2030 CO$_2$, K Tons, Daily	Percent Change in CO$_2$ vs. 2030 CAFE
New York-Newark	5.8	8.7	-1.0	128.5	-0.9
San Francisco-Oakland	4.5	6.8	-0.8	68.1	-0.7
Madison	5.7	8.6	-1.0	6.7	-0.7
Philadelphia	3.5	5.3	-0.6	45.7	-0.5
Albany	3.4	5.1	-0.6	9.1	-0.5
Lancaster, PA	3.5	5.3	-0.6	3.7	-0.5
Chicago	2.8	4.2	-0.5	65.3	-0.4
Washington	2.9	4.4	-0.5	55.8	-0.4
Seattle-Tacoma	2.8	4.2	-0.5	33.2	-0.4
Denver-Aurora	2.4	3.6	-0.4	35.0	-0.4
Portland, OR	2.8	4.2	-0.5	9.5	-0.4
Providence-Fall River	2.6	3.9	-0.5	8.2	-0.4
Spokane	2.7	4.1	-0.5	5.2	-0.4
Los Angeles-Long Beach	2.4	3.6	-0.4	165.6	-0.3
San Diego	1.9	2.9	-0.3	36.3	-0.3
Minneapolis-St. Paul	2.2	3.3	-0.4	29.7	-0.3
Milwaukee	2.5	3.8	-0.4	16.8	-0.3
Sacramento	2.2	3.3	-0.4	29.1	-0.3
Bridgeport-Stamford	2.4	3.6	-0.4	9.1	-0.3
Rochester, NY	2.0	3.0	-0.4	8.5	-0.3
Albuquerque	2.0	3.0	-0.4	9.4	-0.3
Grand Rapids	1.9	2.9	-0.3	9.8	-0.3

Table 30: CO_2 Impact of Increasing Walk-to-Work Shares by 50%

Region *(in order by Percent Reduction in CO_2)*	2005 WTW Share	2030 WTW Share	Percent Change in VMT	2030 CO_2, K Tons, Daily	Percent Change in CO_2 vs. 2030 CAFE
Salem, OR	2.0	3.0	-0.4	2.3	-0.3
Fort Collins	2.3	3.5	-0.4	6.2	-0.3
Miami	1.7	2.6	-0.3	55.1	-0.2
Dallas-Fort Worth	1.3	2.0	-0.2	86.8	-0.2
Houston	1.4	2.1	-0.2	94.1	-0.2
Atlanta	1.1	1.7	-0.2	67.5	-0.2
Phoenix-Mesa	1.6	2.4	-0.3	74.5	-0.2
St. Louis	1.3	2.0	-0.2	29.0	-0.2
Tampa-St. Petersburg	1.5	2.3	-0.3	33.6	-0.2
Orlando	1.3	2.0	-0.2	25.0	-0.2
Louisville	1.4	2.1	-0.2	17.8	-0.2
Jacksonville	1.6	2.4	-0.3	18.9	-0.2
Richmond-Petersburg	1.4	2.1	-0.2	12.7	-0.2
Dayton	1.8	2.7	-0.3	8.8	-0.2
Austin	1.6	2.4	-0.3	24.9	-0.2
Tulsa	1.5	2.3	-0.3	9.8	-0.2
Baton Rouge	1.8	2.7	-0.3	7.3	-0.2
Columbia, SC	1.5	2.3	-0.3	5.1	-0.2
Raleigh	1.2	1.8	-0.2	16.1	-0.2
Knoxville	1.7	2.6	-0.3	14.3	-0.2
Des Moines	1.5	2.3	-0.3	5.8	-0.2
McAllen	1.7	2.6	-0.3	5.5	-0.2
Ogden-Layton	2.0	3.0	-0.4	6.5	-0.2
Boise City	1.6	2.4	-0.3	6.7	-0.2
Bakersfield	1.1	1.7	-0.2	14.7	-0.1
Cape Coral	0.8	1.2	-0.1	9.4	-0.1
Totals/Averages	2.2	3.3	-0.41	1,446.8	-0.35

We did not estimate the cost of this policy. Many studies indicate that factors such as urban street and housing design, development density and the mix of land uses are key elements in achieving high walk-to-work (or even walk-to-transit) shares in urban areas.[164] Many planners also recognize other benefits from greater walking activity (less non-work vehicle travel, savings in fuel and operating costs, insurance, better health, social benefits, etc.). However there are also social costs of more walking (possibly more pedestrian accidents, lost travel time, etc.). These impacts are beyond our scope. But the costs for the land use changes alone appear to be very high and involve re-making urban landscapes over long time frames. Therefore we have chosen to simply assess the policy's impact rather than its costs.

Opportunities for increasing work-at-home shares are considerably greater. Working at home is increasing more rapidly than walking to work, due to improving telecommunications technologies. Using costs per worker of $5,000 to $2,000 according to the size of the region to represent the costs of incentives or services to induce more working at home, we estimate that a substantial increase in work-at-home shares would cost on average about $3,496 per ton of CO_2 emissions reduced (Table 29 above).

Table 31 shows how this policy's impact varies by region. The regions with the greatest relative impact are those that have a currently high work-at-home share; these are typically a mix of smaller university and larger high-tech regions. Some smaller regions (Ft. Collins, Austin, Raleigh, Spokane and Boise) join several other larger regions (SF, Denver, Portland, OR) as likely to yield a 0.7% or better decrease in CO_2 emissions from an aggressive work-at-home strategy.

Table 31: CO_2 Impact of a 50% Increase in Work-at-Home Share

Region (in order by Percent Change in CO_2)	2005 Work at Home Share	2030 Work at Home Share 50% Higher	Percent Change in VMT	Daily CO_2, K Tons	Percent Change vs. 2030 CAFE	Annual Cost, $M	Cost per Ton Reduced
Fort Collins	5.9	8.85	-1.0	6.1	-0.9	$25	$1,834
San Francisco-Oakland	5.1	7.65	-0.9	68.0	-0.7	$553	$4,354
Denver-Aurora	4.7	7.05	-0.8	34.9	-0.7	$183	$3,022
Portland	5.0	7.5	-0.9	9.5	-0.7	$114	$6,680
Austin	4.9	7.35	-0.9	24.8	-0.7	$69	$1,555
Raleigh	5.0	7.5	-0.9	16.0	-0.7	$39	$1,438
Spokane	5.2	7.8	-0.9	5.2	-0.7	$12	$1,347
Boise City	5.1	7.65	-0.9	6.7	-0.7	$25	$1,999
Washington	4.2	6.3	-0.7	55.7	-0.6	$354	$4,080
San Diego	4.3	6.45	-0.8	36.2	-0.6	$195	$3,394
Seattle-Tacoma	4.3	6.45	-0.8	33.2	-0.6	$242	$4,868
Atlanta	4.6	6.9	-0.8	67.2	-0.6	$360	$3,382
Minneapolis-St. Paul	4.1	6.15	-0.7	29.7	-0.6	$164	$3,740
Tampa-St. Petersburg	4.4	6.6	-0.8	33.5	-0.6	$60	$1,115
Sacramento	4.5	6.75	-0.8	29.0	-0.6	$63	$1,328
Orlando	4.1	6.15	-0.7	24.9	-0.6	$46	$1,306
Bridgeport-Stamford	3.9	5.85	-0.7	9.1	-0.6	$ 6	$504
Ogden-Layton	4.6	6.9	-0.8	6.5	-0.6	$13	$1,420
New York-Newark	3.4	5.1	-0.6	128.9	-0.5	$861	$5,209
Los Angeles-Long Beach	3.8	5.7	-0.7	165.2	-0.5	$1,013	$4,501
Dallas-Fort Worth	3.6	5.4	-0.6	86.5	-0.5	$385	$3,657
Phoenix-Mesa	4.0	6	-0.7	74.3	-0.5	$ 226	$2,516
Albuquerque	3.8	5.7	-0.7	9.4	-0.5	$17	$1,449
Chicago	3.3	4.95	-0.6	65.2	-0.4	$386	$5,504
Philadelphia	3.1	4.65	-0.5	45.7	-0.4	$214	$4,349
Miami	3.1	4.65	-0.5	55.0	-0.4	$328	$5,415
Houston	2.8	4.2	-0.5	93.9	-0.4	$292	$3,222
St. Louis	3.0	4.5	-0.5	28.9	-0.4	$77	$2,663
Milwaukee	3.0	4.5	-0.5	16.8	-0.4	$64	$3,703
Providence-Fall River	2.6	3.9	-0.5	8.2	-0.4	$28	$3,366
Jacksonville	2.7	4.05	-0.5	18.9	-0.4	$14	$777
Richmond-Petersburg	2.9	4.35	-0.5	12.7	-0.4	$17	$1,281
Rochester, NY	2.3	3.45	-0.4	8.5	-0.4	$14	$1,813
Albany	2.5	3.75	-0.4	9.1	-0.4	$7	$822
Tulsa	2.7	4.05	-0.5	9.8	-0.4	$11	$1,177
Knoxville	3.1	4.65	-0.5	14.3	-0.4	$13	$843
Des Moines	2.5	3.75	-0.4	5.8	-0.4	$10	$1,835
McAllen	3.0	4.5	-0.5	5.4	-0.4	$ 9	$1,680
Madison	3.3	4.95	-0.6	6.8	-0.4	$5	$658
Cape Coral	3.0	4.5	-0.5	9.3	-0.4	$11	$1,090
Lancaster, PA	2.9	4.35	-0.5	3.7	-0.4	$ 8	$2,132
Louisville	2.1	3.15	-0.4	17.7	-0.3	$11	$927
Grand Rapids	2.4	3.6	-0.4	9.8	-0.3	$10	$1,294
Columbia, SC	2.0	3	-0.4	5.1	-0.3	$7	$1,987
Bakersfield	2.5	3.75	-0.4	14.7	-0.3	$12	$1,072
Salem, OR	2.6	3.9	-0.5	2.3	-0.3	$3	$1,721

Table 31: CO_2 Impact of a 50% Increase in Work-at-Home Share

Region (in order by Percent Change in CO_2)	2005 Work at Home Share	2030 Work at Home Share 50% Higher	Percent Change in VMT	Daily CO_2, K Tons	Percent Change vs. 2030 CAFE	Annual Cost, $M	Cost per Ton Reduced
Dayton	1.7	2.55	-0.3	8.8	-0.2	$6	$1,258
Baton Rouge	1.7	2.55	-0.3	7.3	-0.2	$6	$1,571
Totals/Weighted Average	3.5	5.3	-0.5	1,444.3	-0.5	$6,585	$3,497

In summary, policies to increase non-vehicle commuting shares (walk-to-work, work-at-home) are likely to have only a small impact on CO_2 emissions. For most regions, the impact of a very large increase in walking to work would yield only a modest reduction in CO_2 emissions, primarily because this policy is likely to be very expensive and because current walk-to-work shares are quite low. On the other hand, a similar percentage increase in working at home is both technologically more feasible and likely to be less expensive. This strategy has particular application in communities that are heavily wired already or have a strong university presence relative to city size.

L. Vehicle Size

Primarily because they weigh less, smaller cars generally have higher fuel economies than larger ones, but the difference is not as large as is commonly thought. According to vehicle sales records, the sales-weighted CAFE of smaller cars, over the period 2000–2007, was about 30.7 MPG, about 3.2 MPG higher than the overall CAFE standard of 27.5, but only 4.9 MPG higher than the fuel economy of larger cars, 25.8.

Table 32: Shares and Fuel Efficiencies of Passenger Vehicles

Type	Share of Fleet	Average CAFE MPG, 2007 Model Year	Forecast MPG CAFE 2030 Model Year
Small cars	0.200	30.7	37.3
Mid-Sized cars	0.180	29.0	35.2
Large cars	0.093	25.8	31.3
Wagons	0.057	26.7	32.4
Pick-up/Van/SUV	0.470	21.5	35.0

Source: Transportation Energy Data Book 27

Although the fuel economies of (personal use) light trucks are currently about 25% less efficient (CAFE 21.5) than the overall car fleet (CAFE 28.8, actually higher than the standard, 27.5), the new CAFE standards call for increasing both MPGs to 35 MPG by 2020. The Obama administration has increased this to 35.5 MPG by 2016. Within the car fleet, small cars average about 30.7 MPG, mid-sized cars 29 MPG, large cars 25.8 MPG and wagons 26.7 MPG, as shown in the table above. So, shifting fleet shares from larger to smaller cars would produce some gains in efficiency.

A National Highway Traffic and Safety Administration statistical report for fuel economy cites a loss of 0.01 MPG in fuel economy for every three- to four-pound increase in vehicle weight, according to their weight-versus-fuel-economy algorithms.[165] This implies that a 300–400 pound weight difference would yield about a one MPG difference in fuel economy. However, there is an ever-present concern that reduced weight with increased fuel economy may come with reduced vehicle safety. NHTSA also deduces safety/weight effects of 0.024 to 0.032 MPG or more for current and future (CAFE) standards.

Even though it is widely recognized that a shift from larger to smaller vehicles would clearly lead to less fuel use and to less CO_2 emissions, until recently U.S. consumers still seemed to generally prefer larger vehicles. That may have changed with the 2007 model year, which showed a drop in SUV and truck demand to below 40% of sales, related perhaps to gasoline prices approaching $4/gallon, and the weakening economy. However, gasoline prices moderated to the $2.00 range in 2008, but more recently have risen into the $2.80–3.00 range. In spite of this rise, SUV-light truck sales have rebounded as a share, to about 45%. Although the economy is currently weak and credit limits may affect some purchases, it is difficult to predict consumer preferences for the years ahead. Many analysts do not see a huge consumer shift away from SUVs or light trucks, unless gasoline prices return to the $4/gallon range. Recent (2010) sales have been quite strong for light trucks.

Rather than attempt to predict specific consumer shares of vehicle purchases in the distant future, we instead assess the impact of specific car size mixes. The objective of this assessment is to determine the effect on CO_2 emissions of a significant shift from light trucks and SUVs to more fuel-efficient cars. (Commercial vehicles would not be affected. While their efficiencies will also be improving, there is no talk of shifting commercial loads to smaller vehicles solely for air pollution or CO_2 emissions control purposes.)

In our evaluation, we first developed data on the share of the U.S. private-household vehicle fleet by type/size (small car, mid-size cars, large cars, wagons and light trucks (pick ups/SUVs/vans) using the Transportation Energy Data Book, 2008, Table 4.8. Light trucks (PU/Van/SUVs) are about 47% of the personal car fleet. Even 2008 model year light truck sales were 48% of that year's sales. We then obtained average CAFEs for each group, from the same source (see column 3 in the table above). This assumes that all vehicles within each class have the same MPG.

Beginning with the new CAFE forecast (to 35 MPG by 2020), we estimated the future CAFE for each vehicle group, by scaling up the current CAFE to the future. This assumes that all sub-classes of cars will be improving their efficiencies proportionally; in reality the larger cars might improve more, so this approach understates the potential savings somewhat. We then tested several alternate distributions of vehicles by class and computed the overall CAFE miles-per-gallon, and adjusted for on-the-road efficiency, by reducing "showroom" MPGs for actual driving experience, about 30% less.

For our 48 selected cities, a policy of "1/2 small and 1/2 midsize" cars (no larger cars, SUVs or personal trucks) produces an additional daily CO_2 reduction of about 40,000 tons, or about 2.7%, versus the 2030 CAFE forecast. This seems to be the outer bound of a likely shift in fleet vehicle sizes. An even more extreme case of "all small cars" (no mid-sized or large cars, and no trucks) would yield a decrease of about 71,000 tons daily, or about 4.8%. The results are not as dramatic as one might think because CAFE efficiency for light trucks is *already* required to improve to 35 MPG, so there is little additional impact on fuel efficiency by shifting sales from trucks to cars.

Table 33: Impact of Vehicle Size Mix Polices on CO_2 Emissions

Item	2005	2030 with New CAFEs	2030, with ½ Small and ½ Medium cars	Percent Change vs. 2030 CAFE	2030 with All Small Cars	Percent Change Vs 2030 CAFE
Daily VMT, Million	2,732	4,139	4,139	0%	4,139	0
Daily Fuel, Million Gallons	154.8	161.6	157.1	- 2.78%	153.6	- 4.9
Daily CO_2, Million Tons	1,391	1,453	1413	- 2.71%	1,382	- 4.8
Reduction in CO_2, KT/Day			40		71	

Results are similar for most regions, since we assumed the same vehicle class distribution for each region. If we used different distributions for different cities, some truck-heavy regions might show somewhat smaller reductions, but they would still likely be in the 2% to 3% range.

Table 34: Details of 50/50 Small/Med Cars on CO_2 Emissions

Region *(in order by size)*	2030 CO_2 at Current Size Mix and Future CAFE Standards, K Tons/Day	2030 Fuel Use, ½ Small and ½ Medium Cars, Mil Gallons per Day	2030 CO_2, K Tons/Day	CO_2 Emission Reduction vs. 2030 CAFE, K Tons/Day	Percent Change in CO_2 vs. 2030 CAFE
New York-Newark	129.6	14.095	125.9	3.8	-2.9
Los Angeles-Long Beach	166.2	18.025	161.6	4.6	-2.8
Chicago	65.5	7.045	63.9	1.7	-2.5
Philadelphia	45.9	4.969	44.7	1.2	-2.7
Miami	55.3	5.993	53.8	1.5	-2.8
San Francisco-Oakland	68.6	7.438	66.7	1.9	-2.8
Washington	56.1	6.091	54.5	1.6	-2.9
Dallas-Fort Worth	87.0	9.382	84.7	2.3	-2.6
Houston	94.3	10.193	91.8	2.5	-2.7
San Diego	36.5	3.961	35.4	1.0	-2.9
Seattle-Tacoma	33.4	3.615	32.5	0.9	-2.7
Atlanta	67.7	7.316	65.9	1.8	-2.7
Minneapolis-St. Paul	29.9	3.229	29.0	0.8	-2.8
Phoenix-Mesa	74.7	8.009	72.9	1.8	-2.3
St. Louis	29.1	3.134	28.3	0.8	-2.6
Tampa-St. Petersburg	33.7	3.660	32.8	1.0	-2.8
Denver-Aurora	35.1	3.800	34.1	1.0	-2.9
Milwaukee	16.8	1.800	16.4	0.4	-2.6
Portland, OR	9.6	1.039	9.3	0.3	-2.8
Providence-Fall River	8.3	0.900	8.0	0.2	-3.0
Sacramento	29.3	0.317	28.4	0.8	-2.8
Orlando	25.1	2.713	24.4	0.7	-2.7
Louisville	17.8	1.910	17.4	0.4	-2.5
Jacksonville	19.0	2.050	18.4	0.5	-2.7
Bridgeport-Stamford	9.1	0.986	8.9	0.3	-2.8
Richmond-Petersburg	12.7	1.374	12.4	0.3	-2.8
Rochester, NY	8.5	0.928	8.3	0.3	-3.0
Dayton	8.8	0.949	8.6	0.2	-2.6
Austin	25.0	2.714	24.3	0.7	-2.8
Albany	9.1	0.989	8.9	0.3	-2.8
Albuquerque	9.5	1.020	9.2	0.2	-2.5

Table 34: Details of 50/50 Small/Med Cars on CO_2 Emissions

Region *(in order by size)*	2030 CO_2 at Current Size Mix and Future CAFE Standards, K Tons/Day	2030 Fuel Use, ½ Small and ½ Medium Cars, Mil Gallons per Day	2030 CO_2, K Tons/Day	CO_2 Emission Reduction vs. 2030 CAFE, K Tons/Day	Percent Change in CO_2 vs. 2030 CAFE
Tulsa	9.8	1.064	9.6	0.3	-2.7
Grand Rapids	9.9	1.064	9.6	0.3	-2.7
Baton Rouge	7.3	0.786	7.2	0.2	-2.4
Columbia, SC	5.1	0.548	5.0	0.1	-2.6
Raleigh	16.1	1.739	15.7	0.4	-2.6
Knoxville	14.3	1.546	14.0	0.4	-2.7
Bakersfield	14.7	1.581	14.4	0.3	-2.4
Des Moines	5.9	0.634	5.7	0.2	-2.8
Spokane	5.3	0.568	5.1	0.1	-2.6
McAllen	5.5	0.591	5.3	0.1	-2.7
Ogden-Layton	6.5	0.698	6.3	0.2	-2.4
Madison	6.8	0.730	6.6	0.2	-2.5
Cape Coral	9.4	1.014	9.1	0.3	-2.7
Lancaster, PA	3.7	0.396	3.6	0.1	-2.7
Boise City	6.7	0.728	6.5	0.2	-2.8
Salem, OR	2.3	0.244	2.2	0.1	-2.6
Fort Collins	6.2	0.673	6.0	0.2	-2.9
Total/Average	1,452.5	157.1	1,413	39.5	-2.72

These forecasts also assume no VMT rebound effect (increasing VMT as vehicle efficiency increases). This effect is thought to influence travel by permitting drivers to travel farther on less fuel. As noted in our discussion of VMT reductions, recent research suggests that the effect may be small and may decline with income. Since clearly its effect would be to mute this decrease in emissions further, the above estimates are likely to be optimistic. If it were included (at an elasticity of -0.15, say) the above results would be about 15% lower in emission reduction.

We have not done a cost analysis on these scenarios, since they seem to be negative in cost (actually saving consumers money in the form of lower car costs for smaller vehicles). Governments, of course, might actually lose revenue through less fuel use and lower car costs. However, some analysts think that smaller, fuel-efficient cars might even cost *more* than larger cars because of design and manufacturing issues. Regardless, consumers do incur other real costs in these choices, including less choice in car characteristics, less room, power, perhaps safety, less freedom, etc. These are all very real impacts.

M. Consolidated Results for Regions

The above sections assess the impacts of various policies on CO_2 reduction, and show results in the aggregate and for each of 48 regions. This section summarizes the policies for each region, so that regional planners can compare potential policies for their areas. Collecting the results of the evaluations for each region, the following table summarizes the potential CO_2 percent reduction for various policies in each region. (The appendix contains detailed charts and discussion regarding the emission reduction effect of policies for each region.)

The table is best described with an example. Under the prior CAFE standards, New York-Newark would see about a 37.6% increase in VMT between about 2005 and 2030, with a proportional increase in CO_2 emissions. In other words, if the new CAFE standards were not in place, New York-Newark would have to reduce future CO_2 emissions about 27.3% to hold CO_2 at 2005 levels. However, the new CAFE standards are likely to reduce about 31.2% of 2030 CO_2 emissions, slightly more than needed.

Since the regions vary widely in growth rates and modal shares, some are quite well positioned to meet possible CO_2 reductions, while others would not be able to do so without very large changes in travel behavior. This finding is highlighted by the colors in the last column of Table 35:

🟩	CAFE emission reduction exceeds VMT growth.
🟨	CAFE emission reduction plus some policies may exceed VMT growth.
▨	CAFE emission reduction *and* all policies will likely fall short of VMT growth.
🟥	VMT growth significantly exceeds CAFE emission reduction *and* all policies.

Similar information for all regions is shown in Figure 8 and Table 35 below, which indicate both the relative size and the magnitude of emission reduction. In the figure, regions that *have more than half of their circle in blue (Houston, Phoenix, Austin, Raleigh, Bakersfield and Cape Coral) are particularly at risk,* since the emission reduction from the new CAFE standards, combined with all other emission reduction, would not be enough to hold CO_2 at 2005 levels.

Figure 8: VMT Growth and CO_2 Reduction from Policies

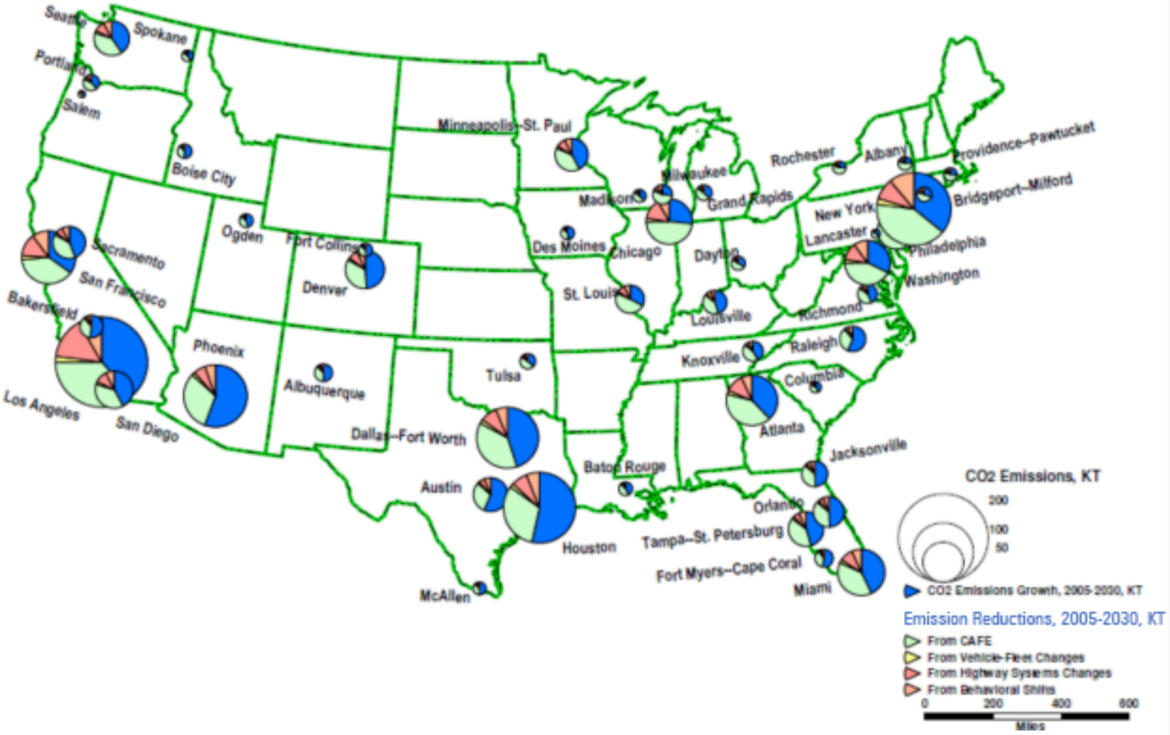


Table 35: Regional Growth in CO_2, 2005-2030, and Percent Reduction from Policies

Region (in size order)	% Change in CO_2 with NO new CAFE	% Reduction to Meet 2005 Level	% Reduction from New CAFE Standards	Added %Reduction Needed to Meet 2005 Level	% Reductions from Med-Small Cars	% Reductions from Signal Timing	% Reductions from 50 mph peak speed	% Reductions from 55 mph speed limit	% Reduction from NO LOS F	% Reductions from 50% more Work at Home	% Reductions from 2x HOV/T Lane	% Reductions from 25% more Carpool	% Reductions from -5 % VMT	% Reductions from +50% Transit	% Red from +50% Walk-to-Work	All	% Excess or Deficit
New York-Newark	37.6	27.3	31.2	0.0	2.9	2.1	1.1	3.0	3.7	0.5	0.1	0.6	4.3	4.6	0.9	23.8	23.8
LA-Long Beach	49.7	33.2	31.2	1.9	2.8	2.4	2.5	3.8	8.5	0.5	2.2	0.9	4.1	0.8	0.3	28.7	26.8
Chicago	21.0	17.4	31.3	0.0	2.5	2.9	1.0	2.2	6.8	0.4	0.3	0.6	3.7	1.5	0.4	22.2	22.2
Philadelphia	26.5	21.0	31.3	0.0	2.7	2.2	0.5	2.3	2.6	0.4	0.2	0.6	3.9	1.3	0.5	17.3	17.3
Miami	53.0	34.6	31.2	3.4	2.8	3.0	0.6	2.2	4.5	0.4	0.4	0.7	4.0	0.5	0.2	19.4	16.0
San Francisco-Oakland	40.0	28.6	31.2	0.0	2.8	2.6	2.2	4.4	6.4	0.7	2.1	0.8	4.1	2.3	0.7	29.2	29.2
Washington	31.6	24.0	31.2	0.0	2.9	2.7	1.1	2.7	6.5	0.6	1.1	0.9	4.2	2.3	0.4	25.5	25.5
Dallas-Fort Worth	59.4	37.3	31.3	6.0	2.6	1.9	1.1	3.3	3.8	0.5	0.4	0.8	3.8	0.3	0.2	18.7	12.7
Houston	112.8	53.0	31.3	21.8	2.7	2.1	1.2	3.4	3.5	0.4	0.7	0.9	3.9	0.4	0.2	19.3	-2.4
San Diego	54.1	35.1	31.2	3.8	2.9	1.9	2.1	4.8	3.6	0.6	0.9	0.8	4.2	0.5	0.3	22.5	18.7
Seattle-Tacoma	47.6	32.2	31.3	1.0	2.7	2.3	0.9	3.0	4.8	0.6	0.9	0.8	4.0	1.1	0.4	21.4	20.4
Atlanta	41.1	29.1	31.3	0.0	2.7	2.9	1.0	2.7	5.6	0.6	0.5	0.7	3.9	0.5	0.2	21.4	21.4
Minneapolis-St. Paul	50.7	33.6	31.2	2.4	2.8	2.4	0.9	3.3	3.5	0.6	0.4	0.6	4.1	0.7	0.3	19.6	17.2
Phoenix-Mesa	125.2	55.6	31.3	24.3	2.3	1.9	0.9	2.5	3.5	0.5	0.6	0.9	3.4	0.3	0.2	17.0	-7.4
St. Louis	26.6	21.0	31.3	0.0	2.6	2.2	0.8	3.0	2.0	0.4	0.1	0.6	3.8	0.4	0.2	16.0	16.0
Tampa	55.9	35.9	31.2	4.6	2.8	2.2	0.4	1.5	2.2	0.6	0.1	0.7	4.2	0.2	0.2	15.2	10.6
Denver-Aurora	79.3	44.2	31.2	13.0	2.9	2.4	0.8	2.8	4.0	0.7	0.2	0.7	4.2	0.6	0.4	19.7	6.8
Milwaukee	18.4	15.5	31.3	0.0	2.6	2.2	0.5	2.4	1.2	0.4	0.1	0.6	3.9	0.5	0.3	14.6	14.6
Portland, OR	38.7	27.9	31.2	0.0	2.8	2.2	0.2	2.6	2.1	0.7	0.1	0.8	4.1	1.1	0.4	17.0	17.0
Providence-Fall River	19.4	16.2	31.2	0.0	3.0	2.2	0.7	3.4	1.2	0.4	0.1	0.7	4.4	0.4	0.4	16.8	16.8
Sacramento	54.5	35.3	31.2	4.0	2.8	2.3	0.7	3.4	2.1	0.6	0.4	0.9	4.1	0.3	0.3	18.1	14.0
Orlando	71.0	41.5	31.3	10.3	2.7	2.3	0.3	2.0	1.9	0.6	0.0	0.7	4.0	0.3	0.2	15.0	4.7
Louisville	54.3	35.2	31.3	3.9	2.5	2.4	0.4	3.0	1.6	0.3	0.1	0.5	3.6	0.3	0.2	14.8	10.9
Jacksonville	67.7	40.4	31.3	9.1	2.7	2.2	0.4	2.4	1.1	0.4	0.0	0.7	4.0	0.2	0.2	14.3	5.2
Bridgeport-Stamford	25.0	20.0	31.2	0.0	2.8	2.3	0.5	3.6	2.0	0.6	0.1	0.5	4.0	1.3	0.3	18.0	18.0
Richmond-Petersburg	49.4	33.0	31.2	1.8	2.8	2.2	0.5	3.2	1.1	0.4	0.0	0.7	4.0	0.3	0.2	15.3	13.5
Rochester, NY	16.2	14.0	31.2	0.0	3.0	2.2	0.4	2.7	0.7	0.4	0.0	0.5	4.4	0.3	0.3	14.9	14.9
Dayton	26.4	20.9	31.3	0.0	2.6	2.1	0.4	2.7	0.9	0.2	0.0	0.5	3.8	0.2	0.2	13.7	13.7
Austin	139.1	58.2	31.2	26.9	2.8	2.3	0.7	3.4	1.7	0.7	0.1	0.8	4.2	0.6	0.2	17.5	-9.4
Albany	14.9	12.9	31.2	0.0	2.8	2.2	0.5	3.0	1.0	0.4	0.1	0.6	4.1	0.4	0.5	15.5	15.5
Albuquerque	76.9	43.5	31.3	12.2	2.5	2.2	0.4	2.2	1.4	0.5	0.1	0.8	3.7	0.2	0.3	14.2	1.9
Tulsa	33.0	24.8	31.2	0.0	2.7	2.2	0.4	2.4	1.0	0.4	0.0	0.7	4.0	0.1	0.2	14.1	14.1
Grand Rapids	36.0	26.4	31.3	0.0	2.7	2.2	0.4	2.2	1.2	0.3	0.0	0.7	3.9	0.2	0.3	13.9	13.9
Baton Rouge	45.0	31.0	31.3	0.0	2.4	2.2	0.4	2.1	0.8	0.2	0.0	0.6	3.5	0.2	0.2	12.6	12.6
Columbia	40.0	28.6	31.3	0.0	2.6	2.2	0.5	3.0	1.0	0.3	0.0	0.8	3.8	0.2	0.2	14.6	14.6
Raleigh	123.9	55.3	31.3	24.1	2.6	2.2	0.3	2.0	1.3	0.7	0.0	0.7	3.9	0.1	0.2	14.0	-10.1
Knoxville	43.9	30.5	31.3	0.0	2.7	2.2	0.4	2.3	1.1	0.4	0.0	0.7	3.9	0.1	0.2	14.0	14.0
Bakersfield	82.0	45.0	31.3	13.8	2.4	2.1	0.3	1.7	1.0	0.3	0.0	0.9	3.5	0.3	0.1	12.6	-1.1
Des Moines	70.0	41.2	31.2	9.9	2.8	2.2	0.5	2.5	0.8	0.4	0.0	0.6	4.1	0.1	0.2	14.3	4.3
Spokane	40.9	29.0	31.3	0.0	2.6	2.3	0.4	1.9	0.9	0.7	0.0	0.6	3.9	0.3	0.4	14.0	14.0
McAllen	75.0	42.9	31.3	11.6	2.7	2.1	0.4	2.1	1.0	0.4	0.0	1.1	3.9	0.0	0.2	14.0	2.4
Ogden-Layton	59.5	37.3	31.3	6.1	2.4	2.3	0.7	2.8	0.7	0.6	0.2	0.7	3.5	0.3	0.2	14.5	8.5
Madison	35.0	25.9	31.3	0.0	2.5	2.3	0.5	2.4	0.9	0.4	0.0	0.6	3.7	0.6	0.7	14.5	14.5
Cape Coral	90.0	47.4	31.2	16.1	2.7	2.2	0.2	1.0	1.3	0.4	0.0	0.8	4.0	0.1	0.1	12.7	-3.4

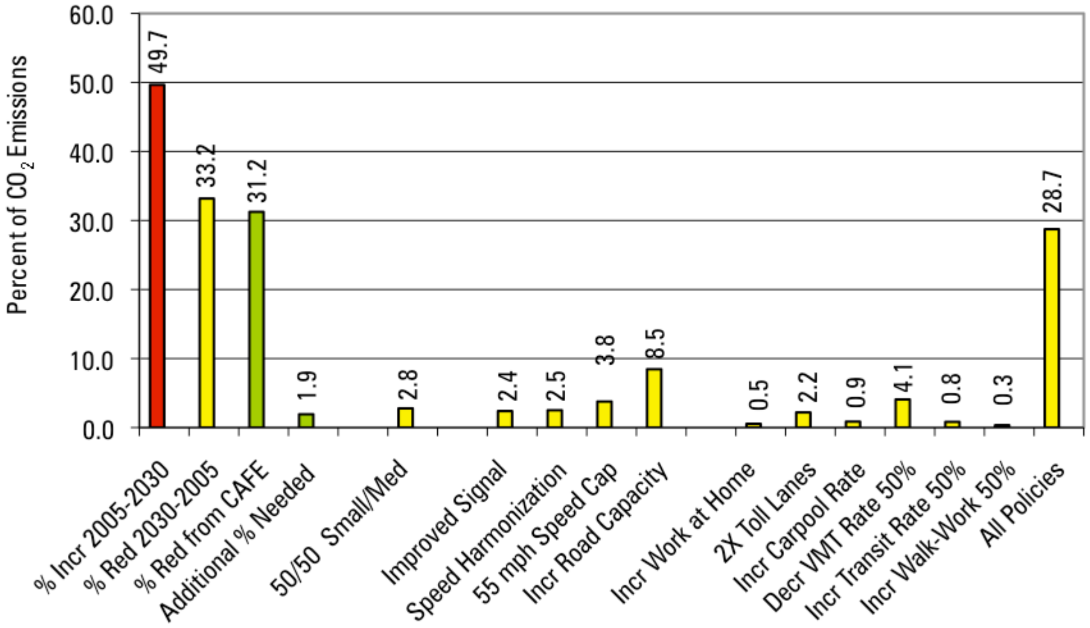
Table 35: Regional Growth in CO_2, 2005-2030, and Percent Reduction from Policies

Region (in size order)	% Change in CO_2 with NO new CAFE	% Reduction to Meet 2005 Level	% Reduction from New CAFE Standards	Added %Reduction Needed to Meet 2005 Level	% Reductions from Med-Small Cars	% Reductions from Signal Timing	% Reductions from 50 mph peak speed	% Reductions from 55 mph speed limit	% Reductions from NO LOS F	% Reductions from 50% more Work at Home	% Reductions from 2x HOV/T Lane	% Reductions from 25% more Carpool	% Reductions from -5 % VMT	% Reductions from +50% Transit	% Red from +50% Walk-to-Work	All	% Excess or Deficit
Lancaster, PA	30.0	23.1	31.3	0.0	2.7	2.2	0.4	1.8	1.0	0.4	0.0	0.7	3.9	0.2	0.5	13.8	13.8
Boise City	78.2	43.9	31.2	12.6	2.8	2.2	0.3	1.7	0.7	0.7	0.0	0.8	4.1	0.1	0.2	13.8	1.2
Salem, OR	50.0	33.3	31.3	2.1	2.6	2.1	0.4	2.5	1.1	0.3	0.0	1.0	3.8	0.3	0.3	14.4	12.3
Fort Collins	72.0	41.9	31.2	10.6	2.9	2.2	0.4	1.9	0.7	0.9	0.0	0.6	4.2	0.1	0.3	14.3	3.7
Totals/Average	51.8	34.1	31.2	2.9	2.7	2.3	1.1	3.0	4.1	0.5	0.6	0.7	4.0	1.1	0.3	20.6	17.7

Three regions (Los Angeles, Phoenix and Milwaukee) are briefly described further as examples.

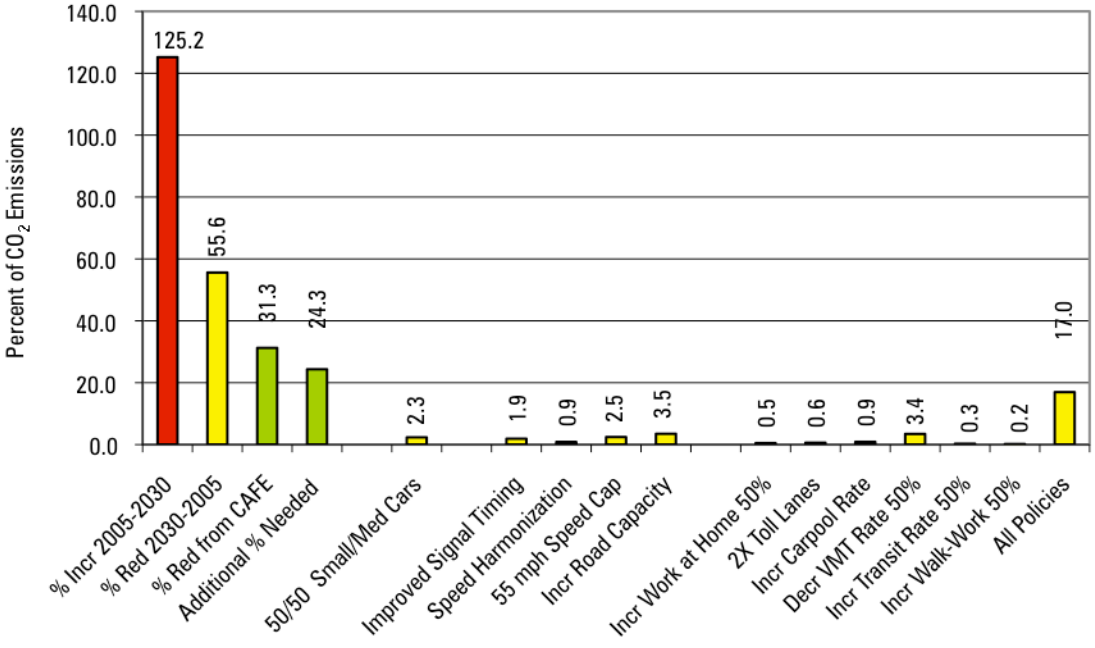
Los Angeles is typical of large regions that are expected to grow moderately over the next several decades. The region's forecast is for traffic (VMT) to grow about 49.7%, implying an increase of 80,200 tons of CO_2 daily. LA would need about a 33.2% emission reduction to hold CO_2 at 2005 levels. About 31.2% CO_2 reduction, which is about 75,500 tons/day, is expected from the new CAFE standards, quite close to needed, leaving about 1.9% (4,700 tons/day) for other policies. If the region wants to hold CO_2 emissions to 2005 levels, it could select additional policies from the chart, which together total 50,100 tons/day, or about 28.7% of CO_2 emissions in potential reduction. However, these actions vary widely in cost-effectiveness and cost.

Figure 9: Los Angeles-Long Beach CO_2 Analysis



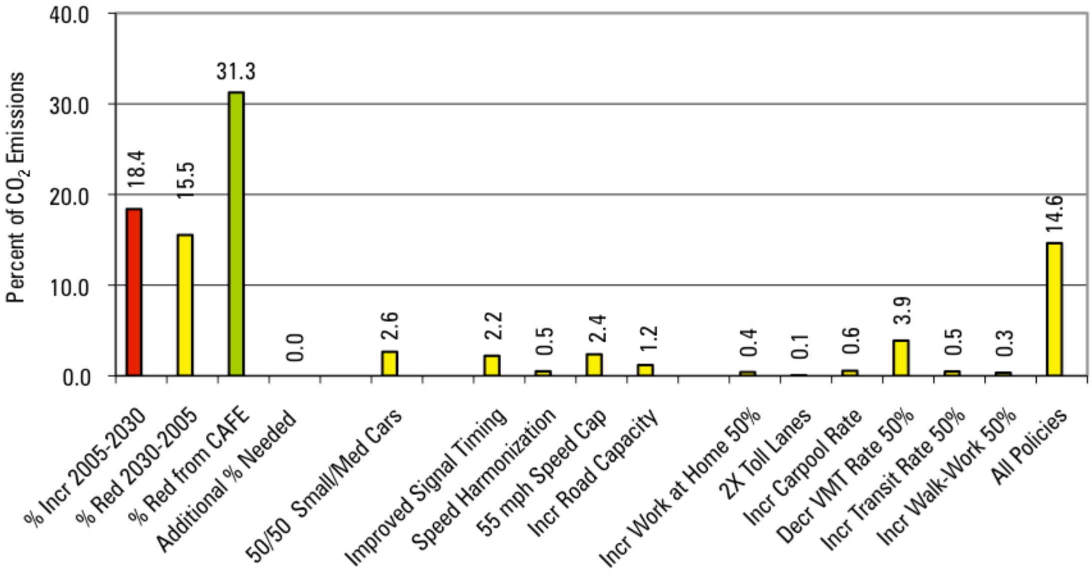
Next, we look at the case of **Phoenix,** a fast-growing region. The region is projected to grow very rapidly, about 125% in VMT over the next several decades, implying an increase of about 60,300 tons of CO_2 daily, so the corresponding need to hold CO_2 at current levels means reducing 55.6% of anticipated 2030 emissions. But only about 31.3% reduction in CO_2 emissions, 33,900 tons/day, can be expected from the new CAFE standards, leaving about 26,400 tons/day, or 24.3%, to be reduced using other policies. However, only about 12,900 tons/day is potentially available from a basket of policies, and only at high cost. Therefore, on its current growth track Phoenix is unlikely to achieve future CO_2 levels below 2005 levels. What actions it should therefore take, if any, depend on its views about the importance of this goal compared with other regional goals.

Figure 10: Phoenix-Mesa CO_2 Analysis



The third case**, Milwaukee,** represents larger regions with slower growth rates. Overall, it is expected to grow about 18.4% in VMT over the next several decades, implying about 3,800 more tons of CO_2 daily, and would therefore need about a 15.5% reduction from projected 2030 emission levels to hold CO_2 emissions to 2005 levels. But the expected changes in fleet efficiency will save about 7,700 tons daily, so Milwaukee is likely to see reduced CO_2 emissions without further actions. If the region contemplates additional actions, they could be selected from the policies shown in the graph, which in total could reduce about 2,500 tons/daily, 14.6% reduction potential, using cost-effectiveness as a key criterion.

Figure 11: Milwaukee CO_2 Analysis



These cases are meant to illustrate a key finding from the study: *one size does not fit all in CO_2 emissions planning, and therefore regions need to balance CO_2 reduction goals with local circumstances, federal actions, cost-effectiveness and other important goals.*

Part 3

Conclusions and Recommendations

A. Conclusions

The major findings of this study are:

1. U.S. man-made carbon dioxide emissions constitute about 21% of global CO_2 emissions.
2. U.S. surface transportation emissions constitute about 6% of global CO_2 emissions.
3. New CAFE standards will result in about a 31% reduction in U.S. surface transportation-related CO_2 emissions by 2030 (1.9% of world CO_2 emissions), compared with prior standards, at a cost of about $52/ton reduced.
4. Regions vary widely in the circumstances that affect their ability to reduce CO_2 emissions. If a policy of reducing carbon dioxide emissions is seen as desirable, it is clear that such emissions reductions should not be imposed uniformly on all regions or sectors. Instead, it would make sense to encourage emissions reduction in the most efficient way possible.
5. If consumers shift sharply to smaller vehicles, an additional reduction of about 2.7% of U.S. transportation emissions (0.16% of global CO_2 emissions) is achievable, even with conventional fuels. Although some shift has been noticed recently, it is not guaranteed to continue and may lag if gasoline prices remain relatively low.
6. Improved signalizations for arterials could yield as much as 2.3% additional savings (0.14% of global CO_2 emissions). The nominal cost of this would be $112 per ton of CO_2 removed. However, there are substantial other benefits to improved signalization, making the reduction in CO_2 essentially an ancillary benefit..
7. Fifty-five-mph speed limits (caps on high freeway speeds) could reduce as much as 3.0% of CO_2 emissions (0.18% of global CO_2 emissions), at a very low cost of $0.13 per ton reduced. However speed caps have very large societal costs in extra travel time.
8. Major road capacity improvements could achieve as much as a 4.1% reduction in CO_2 emissions (0.25% of global CO_2 emissions), but at costs averaging $3,995 per ton reduced. However, there are other reasons for improving capacity (travel time savings, reduced accidents, lower operating costs, greater choices of jobs/housing/retail and economic benefits). The most cost-effective sites are likely to be major bottlenecks and turn lane capacity actions on the minor arterials and collector systems.

9. A 50% increase in work-at-home shares is reducing considerable CO_2 emissions already and has the potential to decrease an additional 0.5% of CO_2 emissions (0.03% of global CO_2 emissions) at about $3,496 per ton reduced.
10. A doubling of HOV lane and stand alone HOT lane mileage could reduce about 0.64% of CO_2 emissions (0.04% of global emissions) but at quite a high price of $2,462 per ton reduced, assuming that new lanes would be needed. This application is probably limited to larger regions.
11. A 25% increase in carpooling-to-work shares could reduce about 0.75% of CO_2 (0.05% of global CO_2 emissions) but also at a relatively high cost of $2,776 per ton reduced, assuming that the increase is in the form of vanpool services. However, carpooling is declining nationally, and so this policy's applicability is probably limited to regions that have a strong history of ridesharing.
12. An across-the-board 5% reduction in personal travel could reduce about 4.0% of CO_2 (0.24% of global CO_2 emissions), but the gasoline price needed to achieve this reduction is in the range of $5/gallon, about $3,923 per ton of CO_2 reduced.
13. Transit service improvements necessary to achieve a 50% increase in transit work shares could reduce about 1.1% of CO_2 emissions (0.07% of global CO_2 emissions) but also at a high price at $4,257 per ton reduced.
14. A 50% increase in walk-to-work shares would yield about a 0.35% reduction in CO_2 (0.02% of global CO_2 emissions), but its implementation is dependent on changing land use patterns, with costs believed to be very high.

In short, policies aimed at reducing transportation-related CO_2 emissions by improving overall fleet fuel efficiency are likely to have the greatest relative and most cost-effective impact. Overall, technological improvements to vehicles resulting in higher fuel efficiency, along with traffic signal timing and speed harmonization, hold out the most hope for significant reductions in future CO_2 emissions. Next in line are policies aimed at improving the efficiency of the transportation system, particularly signal timing and coordination, and speed harmonization. Next in cost-effectiveness are policies aimed at changing commuting behavior, particularly work-at-home policies. Likely to be less effective, both absolutely and relatively, are major capacity increases, more HOV or stand-alone HOT lanes, transit shift policies and carpooling, although in some areas they can provide modest savings.

However, none of the reviewed policies alone, including the new CAFE standards, is likely to reduce global CO_2 emissions by more than about 2%, and most policies would have less than a 0.2% impact on global CO_2 emissions. This means that even if implemented across many U.S. regions in a concerted fashion, the policies reviewed here would not likely have a significant effect on global CO_2 emissions. And at the regional level they may prove very difficult to implement and may not even reduce CO_2 emissions significantly. Given the high relative cost of many policies, therefore, policy makers should not rush to implement them.

B. National Strategy

To the extent that CO_2 reduction in the transportation sector is a goal, the new CAFE standards largely achieves it. Encouraging the purchase of more fuel efficient vehicles is also effective. But both policies are not without significant consequences other than CO_2 reductions, some of them negative.

Most of the strategies being widely discussed in transportation plans—transit increases, VMT reductions, carpooling, pricing, making cities denser and more walk-friendly—would have little measureable effect on regional, national or certainly global CO_2 emissions, even if implemented widely at very high cost. Several other policies—improving CAFE standards even further than presently mandated, encouraging small car purchasing—are beginning to be discussed. Still others—signalization improvements, telecommuting—are being largely ignored even though they have proven effective. National policy should not encourage regions to implement strategies that are not cost-effective.

There is currently significant uncertainty of the potential or cost-effectiveness of various alternative fuels, particularly whether any fuel will expand beyond its current applications and become national in scope. We believe that prudent policy regarding alternative fuels is to focus now on preparing for the mid-term, 15 to 30 years in the future, by concentrating on the reductions achievable with conventional fuels, and letting technologies evolve further. It is simply too risky to determine the impact of individual fuel types at this time.

The nation should agree on and put in place mechanisms for measuring (not just estimating) CO_2 emissions from the transportation sector, perhaps by region and/or mode. These will be necessary to determine progress over time and to set baselines when and if further actions become necessary.

The nation should resist the temptation to mandate CO_2 reduction plans as part of long-range transportation planning. We should not mandate CO_2 reduction targets for regions and states that are based on behavioral shifts. Such activity is likely to be unnecessary, wasteful in staff effort and lead to unrealistic expectations. Instead, national policy should be to encourage study, analysis and quantification of CO_2 emissions in regions, but not mandate actions to deal with them. This is because fleet turnover is likely to significantly mitigate and possibly even reverse the growth of CO_2 emissions in most regions.

C. What Should Regions Do?

Even though the new CAFE standards and possibly more small car sales will reduce the rate of increase in transportation related CO_2 emissions, this strategy will not be enough to achieve significant reductions in CO_2 emissions for some fast-growing regions. Most regions would benefit significantly from major attention to signalization improvements and limited applications of speed harmonization. These policies have significant benefits in terms of saving time for drivers and in the delivery of goods, and while they are not necessarily very cost effective ways of reducing CO_2

emissions, they are less expensive than some other proposed policies. Speed limits are not recommended because of their enforcement problems and large societal costs.

Other policies such as telecommuting, HOV or HOT lanes, carpooling, capacity improvements, VMT reductions and transit service improvements are likely to be even less cost-effective CO_2 emission reducers, although of course there are other reasons for doing some of them. Some slow-growing regions may be able to achieve significant reductions in CO_2 emissions with modest actions in addition to vehicle technology improvements. However, even large "baskets" of policies are not likely to reduce transportation related CO_2 emissions more than about 15 to 20% below our chosen baseline of 2005 levels in most regions, and their effect on global CO_2 emissions is likely not observable. In most regions policy-driven reductions of 20 to 50% are unlikely to be achieved, and therefore long-range plans should be realistic and not be overly optimistic. Particularly, plans should eschew promoting actions related to living patterns or the like, which are not likely to be approved, or be effective if endorsed. Given the wide range of circumstances across regions, the report recommends that all major actions be subjected to a detailed assessment of CO_2 reduction potential versus cost.

In short:

- Regions should understand local circumstances (growth rate, mixes, transit shares, etc.). Slower growing regions are likely to achieve considerable reductions just through fleet turnover.
- Each region should review its opportunities for emission reduction, considering cost-effectiveness.
- Most regions should focus more on work-at-home strategies and on speed-related system improvements such as reducing delays at intersections and on the arterial system. Some might also benefit from speed reduction on fast-flowing facilities, but the loss of time is substantial and can harm economies.
- Regions should resist the temptation to over-hype transit impacts and other "green" actions. Transit impacts are likely to be very small, very costly and cost-ineffective in most regions, particularly those with less than one million people.
- Similarly, most high-capacity additions are likely to be cost-ineffective too. They should be evaluated carefully, looking for possibilities such as turn lanes, signal actions, bottleneck removal and selective widenings.

In conclusion, our assessment finds that significant reductions in CO_2 emissions beyond those already mandated from new CAFE standards are likely to be relatively small, particularly on a global scale, and may be unnecessary.

About the Authors

David T. Hartgen is Emeritus Professor of Transportation Studies at UNC Charlotte and president of The Hartgen Group. Professor Hartgen is widely known in transportation circles. He established the UNC Charlotte's Center for Interdisciplinary Transportation Studies in 1989 and now conducts research in transportation policy. He is the author of about 350 publications on a wide variety of topics in transportation policy and planning, is the U.S. editor of the international academic journal *Transportation,* and is active in professional organizations. He is a frequent media interviewee in local and national publications. Before coming to Charlotte he directed the statistics and analysis functions of the New York State Department of Transportation and served as a Policy Analyst at the Federal Highway Administration. He holds engineering degrees from Duke University and Northwestern University. He has taught at SUNY Albany, Union College and Syracuse University and lectures widely. He is well known for his annual assessments of the cost-effectiveness of the 50 state highway systems. His studies of road conditions and his recent national study of congestion reduction also attracted wide national attention.

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Matthew Scott is an alumnus of Davidson College with an A.B. in Economics. He is currently a post-baccalaureate at UNC Charlotte, and a graduate assistant in Statistics at Johnson C. Smith University. He has contributed to another study in transportation (a review of Charlotte's recently constructed light rail line) in addition to his research in the social sciences.

Elizabeth San Jose is a research analyst with The Hartgen Group. She has contributed to studies of Charlotte's light rail line, congestion in mid-sized regions, congestion growth in mid-sized regions, and Highway Trust Fund revenues. She holds a BS in Aviation Studies from Indiana State University.

Appendix A

Methodology Details

This Appendix expands on the methods used in estimating fuel use and CO_2 emissions.

Baseline Forecast

The goal of this forecast is to estimate how much CO_2 emissions and fuel use will increase if regions grow as forecast and there were no change in fuel economy. Although this is a somewhat artificial pursuit, since new CAFE standards are in place, it forms the basis of determining how much regional growth trends will influence CO_2 emissions.

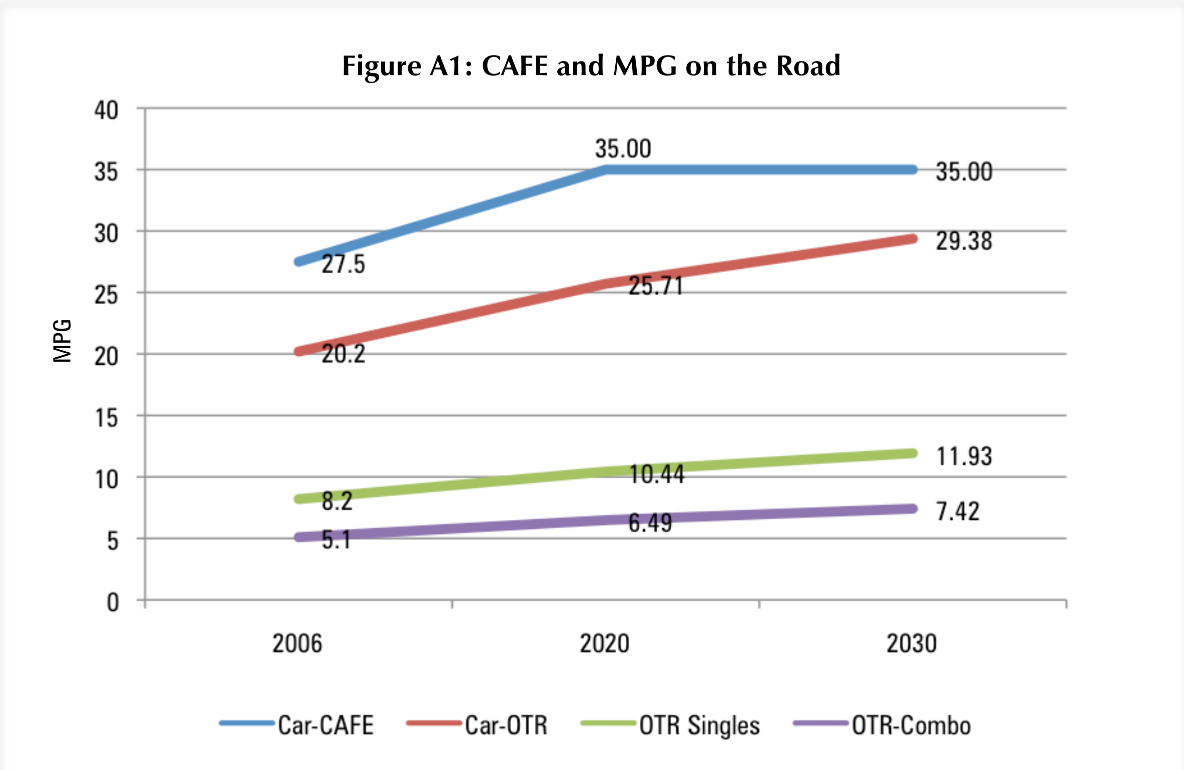
- For each city, we estimated VMT by functional class and vehicle type for 2005 and 2030. This was done by first gathering VMT statistics by functional class from Highway Performance Monitoring System (HPMS) data (as reported in Highway Statistics, 2005). Vehicle class shares by functional class came from special HPMS tabs. The literature provided peak-hour factors (percentage of daily VMT in the highest peak hour). Modal commuting shares for each urbanized area came from the American Community Survey, 2005.
- We made forecasts of VMT by functional class by first trending the VMT by class from 1995 to 2005, then to 2030. Second, using the reported long-range plan (LRP) VMT forecasts for each region as a control, we adjusted VMT by functional class to meet the LRP forecast. We then split the traffic into vehicle types using current (2005) shares and into peak-hour share using the proportions from the literature and from regional travel summaries.
- We estimated fuel use from VMT. Overall average on-the-road fuel use rates are 20.2, 8.1, and 5.1 MPG for cars/light trucks, single-unit commercial trucks and combination-trucks. The Transportation Energy Data Book (TEDB) provided fuel efficiency data. Total fuel use is obtained by adding the fuel consumption for vehicle shares across the functional classes.
- We estimated CO_2 emissions by converting fuel use into emissions, using conversion rates from TEDB. For single-unit trucks, we assumed that half are gasoline and half are diesel.
- Our methodology assumes that the regional LRP plan forecasts of VMT are accurate, that VMT shares and peak-hour shares are constant over time, that fuel efficiency and car/light truck shares are uniform across regions, that CO_2 emissions are a function only of fuel use

and not speed variations within regions, and that lower or higher speeds within regions do not increase as a share of traffic.

New CAFE Standards

We sought to determine what effect the new CAFE standards will have on on-the-road fleet efficiency, fuel use and CO_2 emissions. However, we needed to estimate the average *on-the-road* MPG for the fleet that will be on the road in 2030, but our current data are for 2006 and government benchmarks run only to 2020.

- We looked at the standards the government has considered and implemented over the past few years. Separate figures for single and combo trucks were not mentioned in government analyses. Laws for 2006 set a standard of 27.5 MPG for all passenger vehicles, including light trucks.[166] Our data show that the actual average MPG in 2006 was 20.2. Because the fleet included many older, less gas-efficient vehicles, we expect the actual average to hover below the government benchmark, but approach it over time.
- In the Energy Independence and Security Act of 2007 a CAFE standard of 35 MPG is designated for all *new* vehicles by 2020.[167] To get figures for 2020 and 2030 from the 2006 figures, we assumed a stabilized fleet. The 2006 on-the-road (OTR) MPG is 20.2, compared with a (assumed stabilized) CAFE of 27.5. The ratio is 1.36. In other words, the CAFE rating is 36% higher than the all-factors-considered on-the-road mileage.
- We used the same ratio between the CAFE standard and the actual fleet MPG in the 2006 numbers. To estimate OTR for 2020, we used 1.36 to deflate the 35 MPG requirement in the law to on-the-road use. This yields 25.71.
- To forecast to 2030, assuming that the fleet continues to improve, we "grew" the OTR efficiency to 2030. This yields an estimate of 29.38 on-the-road MPG for 2030.
- For other vehicles, we assume the 2006 OTR efficiency will hold in the future. This assumes that those vehicles will also increase in OTR MPG. This yields 2030 on-the road MPG estimates of 11.93 and 7.42 MPG for single-unit commercial trucks and combination trucks, respectively.
- We then calculated fuel use and CO_2 emission levels by applying these MPG figures to the regional VMT forecasts, by vehicle type and functional class.
- We assumed incremental costs for improved CAFEs to be $900 for cars and light trucks, $2,000 for single-axle combination trucks and $3,000 for heavy trucks, according to a review of the literature. We then converted these into regional estimates using average annual VMT per vehicle, at 15,000 for cars and light trucks, 30,000 for single-axle trucks and 90,000 for heavy trucks.
- This method also assumes the same factors as the baseline forecast, but in addition assumes that fuel efficiency will improve equally in all regions, that on-the-road fuel efficiency will "trend" the future CAFE standards upward, that relative fuel prices will not change demand, and that no CAFE rebound effect will increase VMT.



Highway Capacity Improvements

Our goal was to estimate the effect of improved traffic flow, through capacity increases, on fuel use and CO_2 emissions. Because of the nature of the evaluation, we needed a modified "null" forecast that included speed-specific VMT calculations. We implemented these specific methodological steps:

A. Estimate Null 2030 CO_2 Emissions

- For each region, we estimated peak-hour speed by functional class by dividing speed in the off-peak (free-flow speed) by 2030 TTI (from Reason Congestion Study). We estimated off-peak speeds from typical design standards, e.g.:

  $S_p = 55/1.62$, where 1.62 is the TTI for the region
- We developed look-up tables for cars and light trucks for fuel economy by speed (5-80 mph, at 5 mph increments), using the speed curves (smoothed) in the Transportation Energy Data Book. We developed similar tables for single and combo trucks using estimated curves based on the speed curve above and the ratio of average MPGs for car/light trucks and single trucks and again for cars/light trucks and combo trucks.
- For each region, we then calculated the 2030 average MPG in the peak hour, using the look-up table and CAFE standards with an on-the-road adjustment factor.
- We calculated the 2030 average MPG in the off-peak (OP) hours using the free-flow speed (posted speed limits), the look-up table and the on-the-road adjustment factor.

- We calculated 2030 daily VMT in all peak hours using total 2030 daily vehicle miles traveled (DVMT) (estimated), peak hour shares, numbers of peak hours and the shares of DVMT by vehicle type (cars/light trucks, single trucks and combo trucks). We completed all calculations by functional class: urban interstates (UI), other freeways and expressways (OFE), other principal arterials (OPA), minor arterials (MA), collectors (Col) and local streets (LS).
- We calculated gallons consumed during all peak hours (average peak MPG/peak hr DVMT).
- We calculated 2030 DVMT in all off-peak (OP) hours as (total 2030 DVMT)x(shares of DVMT by vehicle type)/total peak hour DVMT.
- We calculated gallons consumed during all OP hours (average OP MPG/OP hr DVMT).
- We calculated total gallons consumed (gallons in the peak + gallons in the OP).
- We calculated CO_2 emissions in metric tons, using the fuel intensity factor. (Note: for each city this yields an estimate slightly different than the estimates for other tests, since the weighted VMT by speed and fuel use rates by speed do not add up exactly to the aggregate estimates for regions used in other tests. In most cases the differences are small, about 2%.)

B. Determine 2030 CO_2 Emissions, with Congestion Removed

- We calculated gallons consumed in all peak hours (but use the average MPG in the off-peak, divided by the peak hour DVMT), by functional class and vehicle type.
- We calculated gallons consumed in all OP hours (average MPG in the OP/OP DVMT), again by functional class and vehicle type.
- We calculated total gallons consumed by vehicle type (gallons in the peak + gallons in the OP).
- We calculated CO_2 emissions in metric tons by vehicle type, using the fuel intensity factors.

C. Determine the Cost per Ton of Removing CO_2 Emissions through Congestion Removal

- We calculated total gallons consumed with congestion (sum total gallons by vehicle type).
- We calculated CO_2 emissions in metric tons with congestion (sum total emissions by vehicle type).
- We calculated total gallons consumed with congestion removed (sum total gallons by vehicle type).
- We calculated CO_2 emissions in metric tons with congestion removed (sum total emissions by vehicle type).
- We calculated CO_2 emissions reduction from removing congestion (emissions with congestion - emissions with congestion removed).

- We calculated the costs of removing congestion using lane-miles needed to eliminate congestion (from Hartgen and Fields, *Building Roads to Reduce Traffic Congestion)* and estimated costs per lane-mile (based on 2006 HERS-ST data from the Federal Highway Administration).[168] Unit costs vary from about $50 million per lane-mile added for Interstates in high-cost areas to about $2 million per lane-mile added for arterials in low-cost areas.
- We calculated the cost per metric ton of CO_2 reduced (annual projects cost over 20 years/annualized (multiplied by 250) CO_2 emissions reductions).

D. Model Assumptions

- *Peak-hour congestion (TTI index) is the same for all functional classes and is uniform throughout the region*. This is clearly not the case, but more detailed data for each region are not readily available. If available, they would probably show less congestion on most arterials and local systems than we show and more on the interstates, and hence more CO_2 reduction but at higher cost.
- *There is no congestion on weekends*. FHWA's daily VMT data are based on weekday traffic counts; weekend congestion, while clearly present, has not been extensively studied. If included, it would slightly increase the congestion estimates and improve the cost/ton reduced.
- *The percentage of trucks by functional class is the same in the future as in the present*. Since the percentage of trucks on the Interstate system is both higher and rising more rapidly than on other systems, this assumption probably understates the CO_2 to be reduced through capacity actions, and hence if included would also improve the cost/ton reduced estimates.
- *VMT neither increases nor shifts routes in response to added capacity*. This effect, sometimes termed the "induced travel" effect, represents the combined effect of both traffic shifted by route, and "new" traffic. However, it is a minor effect except in major projects, and then for only that portion of the system affected by the project. If included, the effect would slightly increase congestion, and hence lower the speed differential on improved roads and also increase emissions, lowering the estimated decrease in emissions. The effect would be to raise slightly the estimates of cost/ton reduced.
- *Peak-hour factors are assumed to be constant*. In fact, they are slowly declining as regions grow. However, the percentage of traffic in the peak hours is increasing slowly too. These two effects are likely to approximately cancel each other out.
- *On-the-road MPGs vary by speed proportionally as do test-lab MPGs,* and the relationship is the same for cars/light trucks and for single axle and combo trucks. We know of no data indicating otherwise.

Some detailed findings:

Table A1: Fuel Consumption With and Without Congestion

		UI	OFE	OPA	MA	Col	LS
Average Speed (Posted Spd Limit)	mph	55.0	55.0	50.0	45.0	35.0	35.0
Average Speed, Peak Hour	mph	39.1	39.1	35.6	32.0	24.9	24.9
Gallons Consumed With Congestion							
Peak Hours, Cars and Light Trucks	kgal	13,030.0	7,739.5	11,508.2	9,443.9	4,260.7	6,219.5
Peak Hours, Single Trucks	kgal	1,230.6	774.6	1,341.1	908.6	396.7	148.8
Peak Hours, Combo Trucks	kgal	3,232.5	1,191.6	1,170.9	759.0	338.6	125.0
Off-Peak Hours, Cars and Light Trucks	kgal	20,215.4	11,697.8	18,430.2	15,776.4	7,395.37	11,315.2
Off-Peak Hours, Single Trucks	kgal	1,970.6	1,192.9	1,986.6	1,542.1	707.0	260.2
Off-Peak Hours, Combo Trucks	kgal	5,593.7	1,848.5	2,042.3	1,380.8	604.8	227.3
Total		45,272.8	24,444.9	36,479.3	29,810.8	13,703.17	18,296
Without Congestion							
Peak Hours, Cars & Light Trucks	kgal	11,659.8	6,926.1	10,231.2	8,655.5	3,663.9	5,347.4
Peak Hours, Single Trucks	kgal	1,102.3	694.1	1,191.9	832.4	338.8	127.3
Peak Hours, Combo Trucks	kgal	2,903.7	1,069.4	1,045.7	697.5	288.7	107.5
Off-Peak Hours, Cars & Light Trucks	kgal	20,215.4	11,697.8	18,430.2	15,776.4	7,395.3	11,315.2
Off-Peak Hours, Single Trucks	kgal	1,970.6	1,192.2	1,986.6	1,542.1	707.0	260.2
Off-Peak Hours, Combo Trucks	kgal	5,593.6	1,848.5	2,042.3	1,380.8	604.8	227.3
Total		43,445.4	23,428.1	34,927.9	28,884.7	12,998.5	17,384.9
Fuel Savings w/Congestion Removed, K	kgal	1,827.3	1,016.0	1,551.4	926.0	704.6	911.2
CO_2 Reduction w/Congestion Removed	Daily K tons	16.6	9.2	13.9	8.3	6.3	8.0
Cost to Remove Congestion	$M	786,257	194,098	121,266	2,991	129,514	9,290
Cost per Metric Ton of CO_2 Reduced	$	9,486.5	4,244.8	1,744.4	72.3	4,112.2	230.7

Signal Timing

We sought to determine the impact of improved signal timing on fuel consumption and CO_2 emissions.

A. Determine 2030 CO_2 Emissions, Using Same Basic Methodology as Used in the Assessment of Capacity Additions

- We estimated peak-hour speed by functional class by dividing speed in the off-peak (free-flow speed) by 2030 TTI (from Hartgen and Fields, *Building Roads to Reduce Traffic Congestion*, Reason Foundation).
- We developed look-up tables for cars and light trucks for fuel economy by speed (5–80 mph, at 5 mph increments), using the speed curves (smoothed) in the Transportation Energy Data Book. We developed similar tables for single and combo trucks using estimated curves based on the speed curve above and the ratio of average MPGs for car/light trucks and single trucks and again for cars/light trucks and combo trucks.
- We calculated 2030 average MPG in the peak hour using the look-up table and CAFE standards with an on-the-road adjustment factor.
- We calculated 2030 average MPG in the off-peak (OP) hours using the free-flow speed (posted speed limits), the look-up table and the on-the-road adjustment factor.

- We calculated 2030 daily VMT in all peak hours using total 2030 DVMT (estimated), peak hour shares, numbers of peak hours and the shares of DVMT by vehicle type (cars/light trucks, single trucks and combo trucks). We completed all calculations by functional class urban interstates (UI), other freeways and expressways (OFE), other principal arterials (OPA), minor arterials (MA), collectors (Col) and local streets (LS).
- We calculated gallons consumed during all peak hours (average peak MPG/peak hr DVMT).
- We calculated 2030 DVMT in all OP hours = (total 2030 DVMT)x(shares of DVMT by vehicle type)/ (total peak hour DVMT).
- We calculated gallons consumed during all OP hours (average OP MPG/OP hr DVMT).
- We calculated total gallons consumed (gallons in the peak + gallons in the OP).
- We calculated CO_2 emissions in metric tons, using the fuel intensity factor. (Note: for each city this yields an estimate slightly different than the estimates for other tests, since the weighted VMT by speed, and fuel use rates by speed, do not add up exactly to the aggregate estimates for regions used in other tests. In most cases the differences are small, about 2%.)

B. Determine 2030 CO_2 Emissions with Signals Improved

- We assumed an improvement of 15% in the travel flow in peak hours (based on TLC2 report) and reduced the future TTI by 15%[169]
- We assumed an improvement of 10% in the travel flow in off peak hours and reduced the CAFE adjustment factor by 10%.
- We assumed that flow improvements are constrained to the arterial system, and so this study does not reflect improvements in flow on urban interstates, freeways, collectors and local streets.
- We re-calculated CO_2 emissions in metric tons by vehicle type, using the procedures above.
- We calculated total gallons consumed with current signalization (sum total gallons by vehicle type).
- We calculated CO_2 emissions in metric tons with current signalization (sum total emissions by vehicle type).
- We calculated total gallons consumed with improved signalization (sum total gallons by vehicle type).
- We calculated CO_2 emissions in metric tons with improved signalization (sum total emissions by vehicle type).
- We calculated CO_2 emissions reduction from improving signalization (emissions with congestion - emissions with congestion removed).

C. Estimate Costs

- For each city, we determined the numbers of signalized intersections and signals. We divided the 306,177 signalized intersections in the U.S. (106,859 of which were on principal arterials)[170] into urban areas of 50,000 plus and all others assuming a 75/25 split.
- We assumed all urban signals were on the arterial system (principal and minor) and parceled them out to urbanized areas based on their population grouping (very large, large, medium and small) and their share of the arterials (from FHWA statistics).[171]
- Assuming 10 signals per intersection, we calculated total signals per urbanized area.
- For each city, we determined the cost per ton of removing CO_2 emissions through signal improvements, using typical signal improvement costs. We calculated the costs of improving signals, based on the 2007 National Traffic Signal Report Card, Appendix D (National Traffic Signal Report Card 2007); $13,500 every 10 years for intersection controllers, $3,000 every three years per intersection for timing; and one $60,000 technician for every 30 traffic signals.
- We calculated the cost per metric ton of CO_2 reduced.

D. Assumptions

- *The TTI is the same for all functional classes and is uniform throughout the region*. This is clearly not the case, but more detailed data are not readily available. If available, they would probably show less congestion on most arterials and local systems than we show, and more on the interstates, and hence more CO_2 reduction but at higher cost.
- *The percentage of trucks by functional class is the same in the future as in the present*. Since the percent of trucks on the Interstate system is both higher and rising more rapidly than on other systems, this assumption probably understates the CO_2 to be reduced through capacity actions, and hence if included would also improve the cost/ton reduced estimates.
- *VMT neither increases nor shifts routes in response to improved flow and reduced travel times*. This effect, sometimes termed the "induced travel" effect, represents the combined effect of both traffic shifted by route, and "new" traffic. If included, the effect would slightly increase the TTIs, and hence lower the speed differential on signalized arterials, and also increase emissions, lowering the estimated reduction. The effect would be to raise slightly the estimates of cost/ton reduced.
- *Peak-hour factors are assumed to be constant*. In fact, they are slowly declining as regions grow. However, the percentage of traffic in the peak hours is increasing slowly too. These two effects are likely to approximately cancel each other out.
- *On-the-road MPGs vary by speed proportionally as do test-lab MPGs, and the relationship is the same for cars/light trucks and for single axle and combo trucks*. We know of no data indicating otherwise.
- *The effects of signalization coordination on weekend traffic are negligible*. FHWA's daily VMT data are based on weekday traffic models; weekend traffic is not included, so we have excluded weekends from our calculations. If included, the cost per ton reduced would

be somewhat lower. Most of the emissions reduction from signalization improvements come during uncongested periods, since forced changes in speeds come from the signals themselves rather than the surrounding traffic. And improved signalization would reduce some of these forced speed changes.

Speed Controls

The goal of this analysis is to estimate the impact that speed controls would have on fuel use and CO_2 emissions. Specific methodological steps follow:

A. Determine 2030 CO_2 Emissions Using Same Basic Methodology as Used in the Assessment of Capacity Additions

- We determined the "spread" of DVMT by speed increments (bins) during peak hours on urban freeways using data from the Mobility Monitoring Program, Exhibit 10.[172] We estimated the spread for those cities without data, using data from group averages and from similar sized cities. Based on these, we estimated the spread in the off peak, using one spread for all cities.
- We calculated the 2030 DVMT during all peak hours, using total 2030 DVMT (estimated), peak-hour shares, numbers of peak hours and the shares of DVMT by vehicle type (cars/light trucks, single trucks, and combo trucks). We completed this for two functional classes (urban interstates (UI), and other freeways and expressways (OFE)) and added the two totals.
- We calculated the 2030 DVMT on Urban Interstates and Other Freeways and Expressways using the spread and the total DVMT during all peak hours.
- We developed look-up tables for cars and light trucks for fuel economy by speed (5-80 mph, at 2.5 mph increments) using the speed curves (smoothed) in the Transportation Energy Data Book. We developed similar tables for single and combo trucks using estimated curves based on the speed curve above and the ratio of average MPGs for car/light trucks and single trucks and again for cars/light trucks and combo trucks.
- We calculated the 2030 average MPG in the peak hour using the average bin speed, the look-up table and CAFE standards with an on-the-road adjustment factor.
- We calculated the 2030 average MPG in the off-peak (OP) hours using the average bin speed, the look-up table and the on-the-road adjustment factor.
- We calculated gallons consumed during all peak hours (average peak MPG/peak hr DVMT).
- We calculated gallons consumed during all OP hours (average OP MPG/OP hr DVMT).
- We calculated total gallons consumed (gallons in the peak + gallons in the OP).
- We calculated CO_2 emissions in metric tons, using the fuel intensity factor. (Note: for each city this yields an estimate slightly different than the estimates for other tests, since the

weighted VMT by speed and fuel use rates by speed do not add up exactly to the aggregate estimates for regions used in other tests. In most cases the differences are small, about 2%.)

B. Estimate 2030 Emissions with Speed Controls

For each city, we determined the CO_2 emissions for 2030 conditions with maximum speeds capped at 55 mph, calculated the costs to implement this program, and determined the cost per ton of removing CO_2 emissions.

- We set the maximum speed at 55 mph and reran the calculations above. (This reduction affects the top speed bin only.)
- We assumed that this max speed limit will affect two functional classes only: UI and OFE.
- We calculated the costs of replacing and maintaining basic speed limit signs (using a replacement cost of $1,000 per highway mile and a maintenance cost of $50 per highway mile).
- We calculated the total gallons consumed with current speed limits (sum total gallons by vehicle type).
- We calculated CO_2 emissions in metric tons with current speed limits (sum total emissions by vehicle type).
- We calculated total gallons consumed with 55 mph cap (sum total gallons by vehicle type).
- We calculated CO_2 emissions in metric tons with 55 mph cap (sum total emissions by vehicle type).
- We calculated cost per metric ton of CO_2 reduced.

For each city, we determined the CO_2 emissions for 2030 conditions with a speed harmonization program in place (maximum speeds in the peak hour capped at 50 mph), calculated the costs to implement this program, and determined the cost per ton of removing CO_2 emissions.

- We set the maximum speed at 50 mph and reran the calculations above. (This reduction affects the top two speed bins only.)
- We assumed that this maximum speed limit would affect two functional classes only: UI and OFE.
- We calculated the costs of installing new “lane control signals” (LCS) above each lane and replacing and maintaining these signs over time, using an installation cost of $200K per LCS (with 2 LCS per mile, one for each direction) and an annual maintenance cost of $2,000 per LCS. This assumes that the LCS has automatic sensors that can adjust speed limits as congestions warrant.
- We calculated total gallons consumed with current speed limits (sum total gallons by vehicle type).
- We calculated CO_2 emissions in metric tons with current speed limits (sum total emissions by vehicle type).

- We calculated total gallons consumed with 50 mph cap during peak hours (sum total gallons by vehicle type).
- We calculated CO_2 emissions in metric tons with 50 mph cap during peak hours (sum total emissions by vehicle type).
- We calculated cost per metric ton of CO_2 reduced.

C. Assumptions

- *The percentage of trucks by functional class is the same in the future as in the present.* Since the percent of trucks on the Interstate system is both higher and rising more rapidly than on other systems, this assumption probably understates the CO_2 to be reduced through capacity actions, and hence if included would also improve the cost/ton reduced estimates.
- *VMT neither increases nor shifts routes in response to improved flow and reduced travel times.* This effect, sometimes termed "induced travel" effect, represents the combined effect of both traffic shifted by route, and "new" traffic. If included, the effect would slightly increase the TTIs, and hence lower the speed differential on signalized arterials, and also increase emissions, lowering the estimated emission reduction. The effect would be to raise slightly the estimates of cost/ton reduced.
- *Peak-hour factors are assumed to be constant.* In fact, they are slowly declining as regions grow. However, the percentage of traffic in the peak hours is increasing slowly too. These two effects are likely to approximately cancel each other out.
- *On-the-road MPGs vary by speed proportionally as do test-lab MPGs, and the relationship is the same for cars-light trucks and for single axle and combo trucks.* We know of no data indicating otherwise.
- *The effects of speed caps on weekend traffic are negligible.* FHWA's daily VMT data are based on weekday traffic models; weekend traffic is not included, so we have excluded weekends from our calculations. If included, the cost per ton reduced would be much lower for the speed cap approach, but only slightly lower using speed harmonization techniques, since most congestion in the larger urban areas occurs during commuting travel.
- *The costs to highway users due to extended travel times are negligible.* This assumption is clearly not correct, but consumer costs are often overlooked, since they are often not direct. In this case, we estimate annual costs to highway users to be almost $12B for a 55 mph speed cap and over $8B for a 50 mph speed cap during peak hours. These estimates are lowball figures since the former total would increase significantly if weekend travel were considered, and the latter would increase significantly if lower speed limits were set during the peak period, the peak period were to be extended, or the reduced speed limits were used in selected off-peak hours (alternatives that seem likely once the lane control signals are in place).

Reductions in Travel

Our goal was to determine the effect on CO_2 reduction of an “X”% reduction in VMT, or a “Y”% reduction in the growth rate of VMT, in the 48 selected cities and what they might cost.

- We assumed that the policies *would apply only to cars and light trucks*, since there seems to be little political support for a reduction in commercial truck traffic. Typically this is about 90 to 94% of all vehicle traffic. Therefore the VMT reduction policy necessarily results in a lower overall fuel reduction and CO_2 reduction than the stated policy.
- We prepared three tests:
    1. *A 5% reduction in the base-to-future growth rate of car/light truck VMT*. This policy proposes only to *slow the growth rate* of car/light truck VMT by 5%. It typically results in a cut of about 3-5 percentage points in the overall VMT growth rate.
    2. *A 5% reduction in future (2030) car/light truck VMT*. This policy assumes that, on average, about a 5% reduction in VMT by cars and light trucks, is potentially achievable in typical (large and smaller) urbanized areas. It results in a 4% to 4.5% reduction in VMT forecasts for most regions.
    3. *A 10% reduction in future (2030) car/light truck VMT*. This policy seems to be the outer bound of scenario forecasts prepared by the MPOs, about 12%.
- Building on the forecast of VMT, fuel use and CO_2 emissions for the base case, we estimated the lower car/light truck VMT resulting from the policy. This is straightforward, reducing the car/light truck portion by “X”%, applying this to all functional classes, and re-computing the resulting fuel use and CO_2 emissions.
- The cost of the “middle” policy is estimated by calculating a gasoline price rise sufficient to cut car/light-truck VMT by 5% (fuel reduction about 4.7%). We assumed an elasticity of -0.1 (average short-term elasticity of gasoline price with demand, in the literature) and an average price per gallon of $3.50 (high now but might be reasonable for the longer term). For a 4.7% overall cut in fuel use, a price increase averaging 40.7% would be needed, implying a price of about $4.92/gallon. Such a policy would cost consumers in our 48 regions a total of about $227 million/day. This works out to about $3,923 per ton of CO_2 reduced.

HOV and HOT Lanes

Our goal was to determine what the savings would be if HOV-HOT lanes were significantly expanded in the larger U.S. cities and a few of the smaller ones.

- HOV-HOT lanes operate only on Interstates and other freeways, about 2-3% of urban mileage but 30-50 percent of urban traffic (VMT). But they do not cover the entire freeway system and are generally constricted to about 15-25% of a region’s freeways, and that just in the bigger regions (two regions, LA and SF, have larger shares of the system outfitted). They also operate generally in peak hours (two to seven hours per day, depending on the city). When operating, they carry typically 20-30% of the total traffic (vehicles) on the freeway. The speed of operation is faster than on general-purpose lanes, but this advantage is less in smaller, less congested regions. Of our 48 selected cities, 15 have HOV-HOT lanes now, and two others (Raleigh-Durham and Austin) are planning them.

- For each region, we began with the estimated 2030 VMT by functional class, and vehicle type (cars/light trucks, single-axle trucks, combo trucks).
- We then estimated the 2030 VMT that would actually be exposed to HOV-HOT lanes. To do this we used a "squeeze out" method to successively estimate the likely HOV-HOT traffic. The formula is:

  VMT exposed = (2030 Interstate-Freeway Car/Light Truck VMT)x(2030 Percentage of Freeways with HOV/T Lanes)x(Percentage of Freeway VMT Congested)x(Percentage of Congested VMT in HOV/T Lanes)

The first term, "2030 Interstate-Freeway Car/Light Truck VMT," has been estimated prior, in the baseline forecast. The second term, "2030 Percentage of Freeways With HOV-HOT Lanes" is estimated by taking current mileage of HOV/T (based on special summaries provided by FHWA) and adding 100 centerline miles for major cities, 50 centerline miles for smaller cities, down to just three to five centerline miles of HOV-HOT lanes for small cities. This procedure generally doubles the existing HOV-HOT mileage. The third term, "Percentage of Freeway VMT Congested," is the peak hour factor (about 10%) times the number of hours daily that are congested, seven to five for large cities, down to two for smaller ones.

The last term, "Percentage of Congested VMT in the HOV-HOT Lanes," comes from FHWA data showing generally 20-30% AM and PM peak traffic in HOV-HOT lanes, where they exist. For the future, we assumed this to be 25-30% for larger cities, 20% for smaller ones. This is intended to account for some pricing diversion to the lanes, and some mode shifting (a smaller amount) from solo to carpool. We think 25% is probably a high estimate.

- The percentage of the VMT exposed to HOV/T lanes is smaller than one might think, about 20% in LA and SF, 7 to 10 % in Houston, Phoenix, San Diego, DC and Seattle, and less than 4% in other cities. This is because most cities only have 25-35% of traffic in peak hours and the freeway system has only 30-60% outfitted. The big surprise is New York-Newark at 1.9%, but it has only limited HOV/T mileage today and is not likely to increase much.
- The reduction in fuel used and CO_2 generated is dependent on the difference in speed between the HOV-HOT lane and the speed in the general-purpose lanes. We estimated the 2030 congested speed in the general-purpose lanes as:

  $S = 55 \text{ mph}/TTI_f$

  where TTI_f is the estimated 2030 congestion index for the city, from Reason's study of congestion. This calculation assumes that 55 mph is the general-purpose, free-flow operating speed for urban freeways. The estimated congested speeds are in the range of 35-30 mph, lowest for the more congested cities. These speeds also apply to single-unit and combination truck traffic.

- For the HOV-HOT lanes, we calculated fuel use assuming 55 mph for traffic and using fuel use curves, adjusted for on-the-road operation.
- We calculated fuel use for the general-purpose lanes and unexposed lanes (the rest of the freeway system plus other roads) using the regional fuel use average.
- Once fuel use was calculated, we then calculated CO_2 from fuel use, adjusting for diesel trucks.
- Costs of additional HOV-HOT lanes are calculated from FHWA data on freeway lane construction, averaging as much as $50 million per lane-mile (we assumed two lanes per centerline mile) in large high-cost regions to about $5 million to $10 million in smaller, lower-cost regions.
- This method assumes no major additional shifting from solo driving to the HOV-HOT lanes, no induced VMT from the higher speed in the HOV/T lane, and that HOV-HOT percentages on those freeways outfitted will be similar in the future as at present. However it *does* assume a significant increase in HOV-HOT mileage (about 1,681 more centerline-miles), and current (not higher) usage rates for HOV/T lanes as a percentage of freeway traffic. This latter estimate seems low, since there might be some additional use from toll-paying solo drivers), but most cities are not planning on toll lanes, just HOV lanes. Therefore these results are probably more conservative than those calculated using specific toll rates or traffic data for a specific freeway in a specific region.

Transit and Carpooling

Our goal was to estimate the effect of a substantial increase in transit and carpooling commuting, on regional fuel use and CO_2 emissions.

The analysis is muted by realistic information on current and future transit and carpooling shares. A few regions (notably New York-Newark) have greater than 10% urbanized area transit shares, but most have just 1% to 3% transit commuting shares. Most cities have 8% to 12% carpool shares, and these numbers are declining. But work travel (to work and back) is only about 35% of all daily travel. And of course truck traffic would not be affected. The test methodology is:

- **We assumed an increase in carpool shares (not ridership) by 25%.** For instance, if in New York-Newark the current carpool share is 8%, this policy would increase it to 10%. It is difficult to imagine how this could actually happen, short of gasoline rationing or supply cuts or very high parking fees. So this seems like a very high assumption.
- **We also assumed an increase in transit shares (not ridership) by 50%.** In NY, with a 30% transit share at present, this means increasing this to 45%. For most other cities, it means a 1% to 3% increase in the transit share. This might be possible, but only through very large transit expenditures or perhaps gasoline rationing/supply cuts, or possibly major increases in parking fees everywhere.
- We assumed that these increases would *all* come from "drive alone" shares, and reduced solo driving shares accordingly. For NY, this means reducing the drive alone (DA) share

17.2 percentage points, from 50.4% to 33.2%. But for Austin, the change in DA share is from 76.5% down to 71.9%, -4.6 percentage points.

- But work travel (to work and back) is about 35% of all travel. Other private car use would not be affected, nor would weekend travel. And of course single-axle truck and combo truck VMT would not be affected.
- Therefore, the reduction in VMT for cars and light trucks is the reduction in DA share, *times 0.35*. For New York-Newark, this is -6.0%, for Austin this is – 1.61%. This means that even a fairly large (e.g. 50%) increase in transit commuting share would have only a marginal effect on VMT in most cities.
- We computed costs for increasing transit ridership using elasticity of transit ridership to gasoline prices, fare increases and service increase. The elasticity due to service changes is assumed to be about 0.60, in line with the literature. The cost of doing this in each region is the region's average operating cost per revenue vehicle mile, from the National Transit Database, times the number of revenue vehicle-miles needed.
- Costs for increased ridesharing were also obtained from the National Transit Database, using vanpooling costs per vehicle revenue-mile for each region.

Work at Home and Walk to Work

Our goal was to estimate the effect of a substantial increase in walking and work at home telecommuting on fuel use and CO_2 emissions. In most regions, walk-to-work or work-at-home shares are greater than 5%, but most regions have 2% to 4% of their commuters in each category. And of course, work travel (to work and back) is about 35% of all daily travel, and much less of weekend travel. And of course truck traffic would not be affected. The specific steps are:

- **Assume an increase in Walk shares by 50%.** For instance, if in New York-Newark the current walk share is 5.8%, this would increase it to 8.1%. This is a quite high walk share, which would require a lot of land use plan reorganization. So this seems like a very high assumption.
- **Assume an increase in Work-at-Home shares by 50%.** In New York-Newark, with a 3.4% work-at-home share at present, this means increasing this to 5.1%. For most other cities, it means a 1% to 2% increase in the work-at-home share. This might be possible, perhaps through increasing communication and computer technology, perhaps gasoline rationing/supply cuts, or possibly major increases in parking fees everywhere.
- **Assume that all these increases come out of the drive alone share, and reduce that accordingly**. For New York-Newark, this means reducing the DA share 4.6 percentage points from 50.4% to 45.8%. But for Austin, the change in DA share is from 76.5% down to 73.3%, - 3.2 percentage points.

But work travel (to work and back) is about 35% of all travel. Other private car use would not be affected, nor would weekend travel. And of course single-axle truck and combo truck VMT would not be affected. Therefore, we reduced the VMT for cars and light trucks by the reduction in DA share, *times 0.35*. For New York-Newark, this is -1.6%, for Austin this is – 1.1%. This means that even a fairly large (e.g. 50%) increase in walk-to-work and work-at-home shares would have only a marginal effect on VMT in most cities.

We did not estimate the cost of increased walk-to-work shares, but it is thought to be very high. The annual cost of work-at-home increases was estimated based on $1,500 per worker in smaller regions, $2,000 in mid-sized regions and $3,000 in larger regions. This is based on literature from the 1990s indicating costs of about $1,000 per worker, mostly from corporate studies but not including lower productivity.

Vehicle Types

Our goal was to estimate the effect on CO_2 emissions of a significant shift from light trucks and SUVs to more fuel-efficient cars, but with conventional fuels.

Light (personal use) trucks are currently about 25% less efficient (CAFE 21.5) than the overall car fleet (CAFE 28.8, actually higher than the standard, 27.5). However, the new CAFE standards call for increasing *both* MPGs to 35 MPG by 2020. Within the car fleet, small cars average about 30.7 MPG, mid-sized cars 29 MPG, large cars 25.8 MPG, and wagons 26.7 MPG. So shifting fleet shares from larger to smaller cars would produce some gains in efficiency. Commercial vehicles are not affected. While their efficiencies will be improving, there is no talk of shifting loads to smaller vehicles solely for air pollution purposes.

Our specific steps were:

- We developed data on the share of the U.S. private-household vehicle fleet by type/size (small car, mid-size cars, large cars, wagons, and light trucks/pick ups/SUV/van). The source of this data was the Transportation Energy Data Book, 2008, Table 4.8. In this table, the proportion of vehicles (in the fleet), based on seven years of sales, is about:

Type	Share	CAFE07	CAFE30
Small cars:	0.20	30.7	37.27
Mid-Sized cars	0.18	29.0	35.20
Large cars	0.093	25.8	31.32
Wagons	0.057	26.7	32.40
PU/Vans/SUV	0.47	21.5	35.00

So, light trucks (PU/Vans/SUVs) are about 47% of the personal car fleet and this number has been dropping about 1% per year for the past three years. (2008 saw a drop in new truck sales, which will take a few years to work into the fleet). But sales rebounded in late 2009-2010. Ideally one would like to have this data for each region, and it is available (in the air quality models), but obtaining it is beyond the scope of this project. As the results show, more detailed data for each region would probably not change the answer very much.

- We obtained data on average CAFE for each group from the same source (see column three above). This assumes that all vehicles within each class have the same MPG.

- Beginning with the null forecast (to 35 MPG by 2020), we estimated the future CAFE for each vehicle group, by scaling up the current CAFE to the future. (This assumes that all sub-classes of cars will be improving their efficiencies proportionally equally; in reality the larger cars might improve more, so this approach understates the potential savings somewhat.)
- We tested alternative distributions of vehicles by class, and computed overall CAFE, adjusting for on-the-road efficiency.
- The forecasts assume no rebound effect (increasing VMT as efficiency increases). While this effect has been studied in theory, the empirical evidence for such a rebound is sketchy and it may not exist. Since clearly its effect would be to mute these reductions further, the above estimates are likely to be close to the maximum achievable.
- We have not done a cost analysis on these tests, since they seem to be negative in cost (actually saving consumers money in the form of lower car costs for smaller vehicles). However there are of course real costs to these choices, including less choice in car characteristics, less room, power, perhaps safety, less freedom, etc. These are all very real impacts.

Appendix B

Detailed Findings and Regional Summaries

Table A2: 2030 Daily CO_2 Reduction, K tons/day

Region (in order by size)	2005 CO_2 Tons	2030 Null CO_2	Incr. 2005-2030	New CAFE CO_2 Reduction	Addit Reduction Needed	50/50 Sm/Med Car	Signal Timing	Spd Harm. (50 mph in peak)	55 mph Spd Cap	Cap Incr. (Eliminate LOS F)	+50% Work at Home	2x Con-gestion Pricing	+25% Car-pooling	5 % VMT Red	+50% Transit %	+50% Walk-to-Work	All Policies	Excess or Deficit
New York	137.0	188.5	51.5	58.9	0.0	3.8	2.9	1.5	4.1	4.9	0.7	0.2	0.8	5.6	6.0	1.1	31.4	31.4
Los Angeles	161.5	241.7	80.2	75.5	4.7	4.6	4.3	4.5	6.8	15.2	0.9	3.6	1.4	6.8	1.4	0.6	50.1	45.4
Chicago	78.7	95.3	16.5	29.8	0.0	1.7	2.0	0.7	1.5	4.7	0.3	0.2	0.4	2.4	1.0	0.2	15.2	15.2
Philadelphia	52.8	66.8	14.0	20.9	0.0	1.2	1.0	0.2	1.1	1.2	0.2	0.1	0.3	1.8	0.6	0.2	8.0	8.0
Miami	52.6	80.4	27.8	25.1	2.7	1.5	1.7	0.4	1.3	2.6	0.2	0.2	0.4	2.2	0.3	0.1	11.0	8.3
San Francisco	71.2	99.7	28.5	31.2	0.0	1.9	1.9	1.6	3.2	4.7	0.5	1.4	0.6	2.8	1.6	0.4	20.6	20.6
Washington	61.9	81.5	19.6	25.5	0.0	1.6	1.6	0.7	1.6	3.9	0.3	0.6	0.5	2.4	1.3	0.2	14.8	14.8
Dallas-FTW	79.3	126.5	47.1	39.5	7.6	2.3	1.7	1.0	3.0	3.4	0.4	0.3	0.7	3.3	0.2	0.2	16.6	8.9
Houston	64.4	137.1	72.7	42.8	29.8	2.5	2.0	1.1	3.3	3.4	0.4	0.6	0.8	3.7	0.4	0.2	18.5	-11.3
San Diego	34.4	53.0	18.6	16.6	2.0	1.0	0.7	0.8	1.8	1.4	0.2	0.3	0.3	1.5	0.2	0.1	8.3	6.3
Seattle- Tacoma	32.9	48.5	15.6	15.2	0.5	0.9	0.8	0.3	1.0	1.7	0.2	0.3	0.3	1.3	0.4	0.1	7.3	6.8
Atlanta	69.7	98.4	28.6	30.7	0.0	1.8	2.1	0.7	2.0	4.0	0.4	0.3	0.5	2.6	0.4	0.1	15.0	15.0
Minn./St. Paul	28.8	43.4	14.6	13.6	1.0	0.8	0.7	0.3	1.0	1.1	0.2	0.1	0.2	1.2	0.2	0.1	6.0	4.9
Phoenix-Mesa	48.2	108.5	60.3	33.9	26.4	1.8	1.5	0.7	1.9	2.7	0.4	0.5	0.7	2.6	0.2	0.1	12.9	-13.6
St. Louis	33.4	42.3	8.9	13.2	0.0	0.8	0.7	0.2	0.9	0.6	0.1	0.0	0.2	1.1	0.1	0.1	4.7	4.7
Tampa-St. Pete.	31.5	49.0	17.6	15.3	2.3	1.0	0.8	0.1	0.5	0.8	0.2	0.0	0.2	1.4	0.1	0.1	5.2	2.9
Denver-Aurora	28.5	51.1	22.6	16.0	6.6	1.0	0.9	0.3	1.0	1.5	0.2	0.1	0.2	1.5	0.2	0.1	7.1	0.4
Milwaukee	20.7	24.5	3.8	7.7	0.0	0.4	0.4	0.1	0.4	0.2	0.1	0.0	0.1	0.7	0.1	0.1	2.5	2.5
Portland, OR	10.1	13.9	3.9	4.4	0.0	0.3	0.2	0.0	0.3	0.2	0.1	0.0	0.1	0.4	0.1	0.0	1.6	1.6
Providence	10.1	12.0	2.0	3.8	0.0	0.2	0.2	0.1	0.3	0.1	0.0	0.0	0.1	0.4	0.0	0.0	1.4	1.4
Sacramento	27.5	42.5	15.0	13.3	1.7	0.8	0.7	0.2	1.0	0.6	0.2	0.1	0.3	1.2	0.1	0.1	5.3	3.6
Orlando	21.3	36.4	15.1	11.4	3.7	0.7	0.6	0.1	0.5	0.5	0.1	0.0	0.2	1.0	0.1	0.0	3.8	0.1
Louisville	16.8	25.9	9.1	8.1	1.0	0.4	0.4	0.1	0.5	0.3	0.0	0.0	0.1	0.6	0.1	0.0	2.7	1.6
Jacksonville	16.4	27.6	11.1	8.6	2.5	0.5	0.4	0.1	0.5	0.2	0.1	0.0	0.1	0.7	0.0	0.0	2.7	0.2
Bridgeport-Stamf.	10.6	13.3	2.7	4.1	0.0	0.3	0.2	0.0	0.3	0.2	0.1	0.0	0.0	0.4	0.1	0.0	1.7	1.7
Richmond-P-burg	12.4	18.5	6.1	5.8	0.3	0.3	0.3	0.1	0.4	0.1	0.1	0.0	0.1	0.5	0.0	0.0	2.0	1.6
Rochester, NY	10.7	12.4	1.7	3.9	0.0	0.3	0.2	0.0	0.2	0.1	0.0	0.0	0.0	0.4	0.0	0.0	1.3	1.3
Dayton	10.2	12.8	2.7	4.0	0.0	0.2	0.2	0.0	0.2	0.1	0.0	0.0	0.0	0.3	0.0	0.0	1.2	1.2
Austin	15.2	36.4	21.2	11.4	9.8	0.7	0.6	0.2	0.9	0.4	0.2	0.0	0.2	1.0	0.1	0.1	4.4	-5.4
Albany	11.5	13.3	1.7	4.1	0.0	0.3	0.2	0.0	0.3	0.1	0.0	0.0	0.1	0.4	0.0	0.0	1.4	1.4
Albuquerque	7.8	13.8	6.0	4.3	1.7	0.2	0.2	0.0	0.2	0.1	0.0	0.0	0.1	0.3	0.0	0.0	1.3	-0.3
Tulsa	10.7	14.3	3.5	4.5	0.0	0.3	0.2	0.0	0.2	0.1	0.0	0.0	0.1	0.4	0.0	0.0	1.4	1.4
Grand Rapids	10.6	14.3	3.8	4.5	0.0	0.3	0.2	0.0	0.2	0.1	0.0	0.0	0.1	0.4	0.0	0.0	1.4	1.4
Baton Rouge	7.3	10.7	3.3	3.3	0.0	0.2	0.2	0.0	0.2	0.1	0.0	0.0	0.0	0.3	0.0	0.0	0.9	0.9

Table A2: 2030 Daily CO_2 Reduction, K tons/day

Region (in order by size)	2005 CO_2 Tons	2030 Null CO_2	Incr. 2005-2030	New CAFE CO_2 Reduction	Addit Reduction Needed	50/50 Sm/Med Car	Signal Timing	Spd Harm. (50 mph in peak)	55 mph Spd Cap	Cap Incr. (Eliminate LOS F)	+50% Work at Home	2x Congestion Pricing	+25% Car-pooling	5 % VMT Red	+50% Transit %	+50% Walk-to-Work	All Policies	Excess or Deficit
Columbia, SC	5.3	7.4	2.1	2.3	0.0	0.1	0.1	0.0	0.2	0.1	0.0	0.0	0.0	0.2	0.0	0.0	0.7	0.7
Raleigh	10.5	23.4	13.0	7.3	5.6	0.4	0.4	0.1	0.3	0.2	0.1	0.0	0.1	0.6	0.0	0.0	2.3	-3.4
Knoxville	14.5	20.8	6.4	6.5	0.0	0.4	0.3	0.1	0.3	0.2	0.1	0.0	0.1	0.6	0.0	0.0	2.0	2.0
Bakersfield	11.8	21.4	9.6	6.7	3.0	0.3	0.3	0.0	0.2	0.2	0.0	0.0	0.1	0.5	0.0	0.0	1.9	-1.1
Des Moines	5.0	8.5	3.5	2.7	0.8	0.2	0.1	0.0	0.1	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.8	0.0
Spokane	5.4	7.6	2.2	2.4	0.0	0.1	0.1	0.0	0.1	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.7	0.7
McAllen	4.5	8.0	3.4	2.5	0.9	0.1	0.1	0.0	0.1	0.1	0.0	0.0	0.1	0.2	0.0	0.0	0.8	-0.2
Ogden-Layton	5.9	9.4	3.5	3.0	0.6	0.2	0.1	0.0	0.2	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.9	0.4
Madison	7.3	9.9	2.6	3.1	0.0	0.2	0.2	0.0	0.2	0.1	0.0	0.0	0.0	0.3	0.0	0.0	1.0	1.0
Cape Coral	7.2	13.6	6.4	4.3	2.2	0.3	0.2	0.0	0.1	0.1	0.0	0.0	0.1	0.4	0.0	0.0	1.2	-1.0
Lancaster, PA	4.1	5.3	1.2	1.7	0.0	0.1	0.1	0.0	0.1	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.5	0.5
Boise City	5.5	9.8	4.3	3.0	1.2	0.2	0.1	0.0	0.1	0.0	0.0	0.0	0.1	0.3	0.0	0.0	0.9	-0.3
Salem, OR	2.2	3.3	1.1	1.0	0.1	0.1	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.3	0.3
Fort Collins	5.2	9.0	3.8	2.8	1.0	0.2	0.1	0.0	0.1	0.0	0.1	0.0	0.0	0.3	0.0	0.0	0.9	-0.1
Totals	1391.0	2111.7	720.7	659.9	119.9	39.5	35.1	16.7	44.9	62.3	7.5	9.3	10.9	57.8	15.6	5.0	304.5	184.6

Table A3: Incremental Annual Cost for Selected Policies ($US)

Region (in order by Size)	CAFE Total Annual Cost, M$	Signal. Total Ann Cost, M$	Speed Harmon. Total Ann Cost, M$	Capacity Incr. Total Ann Cost, M$	Speed Cap (55mph) Total Ann Cost, M$K	Work-at-Home Total Ann Cost, $M	Congestion Pricing Total Ann Cost, M$	Carpooling Total Annual Cost, M$	VMT Reduction Total Ann Cost, M$	Transit Total Ann Cost, M$
New York-Newark	$812.6	$133.4	$91.6	$4,591.3	$0.2	$861.2	$250.0	$1,241.3	$5,461.5	$5,836.5
Los Angeles-Long Beach	998.3	111.8	50.5	8,975.9	0.1	1,012.7	500.0	1,196.3	6,637.6	1,201.5
Chicago	361.1	76.8	36.3	6,612.8	0.1	385.8	500.0	204.3	2,398.6	1,623.5
Philadelphia	268.2	57.3	35.0	1,889.2	0.1	213.7	500.0	147.7	1,786.8	1,008.3
Miami	329.7	26.0	24.7	6,509.1	0.0	328.1	500.0	274.1	2,189.6	487.1
San Francisco-Oakland	417.5	33.6	20.5	4,556.2	0.0	552.6	150.0	461.2	2,794.4	470.1
Washington	346.5	33.8	24.7	3,035.7	0.0	354.3	400.0	403.8	2,325.5	1,422.4
Dallas-Fort Worth	494.9	40.0	39.2	3,824.9	0.1	384.5	300.0	476.0	3,271.1	431.9
Houston	547.2	40.5	28.3	3,351.1	0.1	291.6	300.0	303.9	3,595.7	387.1
San Diego	224.5	19.3	20.8	1,937.4	0.0	195.0	300.0	172.6	1,495.6	91.6
Seattle-Tacoma	196.0	30.3	24.1	705.6	0.0	242.2	300.0	172.5	1,297.8	502.9
Atlanta	391.9	31.4	27.0	2,896.8	0.1	359.5	300.0	244.8	2,596.2	433.4
Minneapolis-St. Paul	179.0	30.5	24.1	1,981.5	0.0	163.8	300.0	175.0	1,197.2	241.9
Phoenix-Mesa	387.7	22.7	15.1	2,727.9	0.0	225.9	150.0	437.7	2,500.5	130.3
St. Louis	163.4	26.7	26.4	705.0	0.1	76.8	150.0	81.9	1,084.2	219.4
Tampa-St. Petersburg	205.7	14.8	12.0	344.1	0.0	60.1	100.0	121.5	1,371.3	51.7
Denver-Aurora	216.5	19.5	19.4	1,678.3	0.0	183.4	125.0	98.1	1,440.1	440.0
Milwaukee	96.7	23.5	10.6	247.7	0.0	63.5	50.0	30.5	646.1	147.7
Portland	57.6	14.2	11.3	766.5	0.0	114.2	75.0	37.3	384.1	302.8
Providence-Fall River	52.6	17.0	13.7	226.0	0.0	27.6	50.0	35.4	355.9	78.9
Sacramento	176.4	11.8	8.8	679.6	0.0	62.8	50.0	185.3	1,176.6	151.0
Orlando	146.8	10.9	12.5	187.4	0.0	46.4	30.0	93.8	968.7	97.5
Louisville	95.7	7.3	11.2	343.9	0.0	10.9	30.0	48.3	629.4	50.7
Jacksonville	110.9	5.2	11.9	179.1	0.0	13.8	30.0	71.0	733.2	71.8
Bridgeport-Stamford	54.1	7.9	9.2	149.3	0.0	6.3	20.0	71.4	362.6	14.1

Table A3: Incremental Annual Cost for Selected Policies ($US)

Region (in order by Size)	CAFE Total Annual Cost, M$	Signal. Total Ann Cost, M$	Speed Harmon. Total Ann Cost, M$	Capacity Incr. Total Ann Cost, M$	Speed Cap (55mph) Total Ann Cost, M$K	Work-at-Home Total Ann Cost, $M	Congestion Pricing Total Ann Cost, M$	Carpooling Total Annual Cost, M$	VMT Reduction Total Ann Cost, M$	Transit Total Ann Cost, M$
Richmond-Petersburg	75.2	9.7	14.5	45.0	0.0	16.7	20.0	32.7	502.8	32.5
Rochester, NY	54.2	6.2	7.5	188.7	0.0	13.6	20.0	29.1	367.2	55.4
Dayton	49.2	6.3	8.4	110.5	0.0	6.2	20.0	31.1	327.6	51.8
Austin	152.6	4.3	7.7	430.4	0.0	69.3	20.0	120.8	1,008.2	142.7
Albany	55.0	6.0	7.8	170.9	0.0	6.7	15.0	32.1	369.6	49.4
Albuquerque	52.2	5.3	4.8	137.9	0.0	16.8	15.0	33.4	340.9	42.4
Tulsa	58.2	9.1	11.4	244.9	0.0	11.0	15.0	42.9	388.3	15.7
Grand Rapids	56.9	6.3	7.7	51.2	0.0	10.5	7.5	57.9	379.9	29.7
Baton Rouge	38.2	7.8	4.5	104.7	0.0	5.9	7.5	17.2	249.1	26.2
Columbia, SC	28.5	5.7	6.6	59.4	0.0	6.7	7.5	16.9	189.1	9.0
Raleigh	92.4	4.0	6.3	643.0	0.0	39.3	15.0	55.9	608.0	11.0
Knoxville	82.9	5.5	4.7	200.1	0.0	12.9	7.5	39.0	552.5	14.3
Bakersfield	77.1	7.0	3.1	43.4	0.0	12.0	7.5	9.8	499.8	23.5
Des Moines	35.1	8.8	3.8	100.3	0.0	9.6	4.5	11.5	234.2	13.6
Spokane	30.1	8.5	3.1	78.9	0.0	12.4	4.5	13.9	199.2	46.6
McAllen	31.7	5.2	4.3	85.2	0.0	9.4	3.0	24.8	209.1	2.4
Ogden-Layton	34.6	4.0	3.9	91.7	0.0	13.1	30.0	19.5	225.0	34.2
Madison	37.2	4.9	3.9	112.1	0.0	4.7	3.0	22.2	246.2	39.5
Cape Coral	55.1	3.6	2.4	40.8	0.0	10.7	3.0	69.5	363.3	15.2
Lancaster, PA	21.4	5.3	2.6	55.2	0.0	7.8	3.0	10.2	142.4	15.2
Boise City	40.7	5.6	1.8	53.3	0.0	24.8	3.0	21.7	270.9	6.4
Salem, OR	12.7	3.4	2.0	10.0	0.0	3.3	1.5	35.2	83.5	22.1
Fort Collins	38.1	4.2	2.4	10.9	0.0	24.7	1.5	16.8	254.5	9.8
Totals ($US)	$8,540.5	$982.6	$733.8	$62,170.7	$1.5	$6,584.8	$5,694.5	$7,549.9	$56,711.8	$16,602.6

Table A4: Cost Effectiveness: Cost per Ton of CO$_2$ Reduced ($US)

Region	CAFE Cost per Ton Reduced $	Signal. Annual Cost to Gov't per Ton Reduced, $	Speed Harmon. Annual Cost to Gov't per Ton Reduced, $	Capacity Incr. Annual Cost over 20 years per Metric Ton Reduced, $	Speed Cap (55mph) Annual Cost to Gov't per Ton Reduced, $	Work at Home Annual Cost/Ton Reduced $	Congestion Pricing Annual Cost per Ton Reduced $	Carpooling Annual Cost per Ton Reduced $	VMT Reduction Annual Cost per Ton Reduced $	Transit Annual Cost per Ton CO$_2$ Reduced $
New York-Newark	$55.19	$186.14	$244.99	$3,739.41	$0.18	$5,208.82	$6,122.90	$6,545.21	$3,930.87	$3,922.27
Los Angeles-Long Beach	52.88	104.25	44.79	2,365.50	0.06	4,500.58	548.28	3,339.40	3,923.42	3,498.63
Chicago	48.51	152.68	207.89	5,578.90	0.19	5,503.62	11,286.54	2,003.64	3,951.83	6,421.95
Philadelphia	51.38	222.70	591.84	6,147.46	0.26	4,348.69	26,927.72	2,003.64	3,944.54	6,556.81
Miami	52.48	60.04	281.90	9,999.59	0.16	5,415.06	8,899.32	2,671.52	3,921.43	6,923.88
San Francisco-Oakland	53.59	71.58	50.68	3,916.87	0.05	4,354.34	421.97	3,339.40	3,930.18	1,188.03
Washington	54.41	84.72	149.31	3,126.12	0.12	4,080.42	2,508.46	3,339.40	3,937.23	4,382.69
Dallas-Fort Worth	50.09	91.80	153.03	4,540.93	0.10	3,656.79	3,902.53	2,671.52	3,919.79	7,783.06
Houston	51.09	80.03	98.97	3,951.85	0.07	3,222.09	1,924.13	1,469.33	3,893.65	3,742.37
San Diego	54.23	109.68	105.60	5,718.95	0.09	3,394.42	3,611.77	2,370.97	3,918.77	2,212.15
Seattle-Tacoma	51.69	147.72	299.68	1,685.57	0.19	4,868.38	3,977.39	2,571.33	3,926.29	5,719.68

Table A4: Cost Effectiveness: Cost per Ton of CO_2 Reduced ($US)

Region	CAFE Cost per Ton Reduced $	Signal. Annual Cost to Gov't per Ton Reduced, $	Speed Harmon. Annual Cost to Gov't per Ton Reduced, $	Capacity Incr. Annual Cost over 20 years per Metric Ton Reduced, $	Speed Cap (55mph) Annual Cost to Gov't per Ton Reduced, $	Work at Home Annual Cost/Ton Reduced $	Congestion Pricing Annual Cost per Ton Reduced $	Carpooling Annual Cost per Ton Reduced $	VMT Reduction Annual Cost per Ton Reduced $	Transit Annual Cost per Ton CO_2 Reduced $
Atlanta	50.99	59.43	151.76	2,873.11	0.11	3,382.08	3,481.83	2,037.03	3,931.94	4,688.11
Minneapolis-St. Paul	52.80	163.26	346.46	7,392.68	0.19	3,739.70	9,902.78	3,639.94	3,922.26	4,716.89
Phoenix-Mesa	45.72	61.62	91.95	4,064.11	0.06	2,516.08	1,305.06	2,671.52	3,899.59	2,321.49
St. Louis	49.48	163.26	454.29	4,650.89	0.24	2,663.49	19,842.81	2,003.64	3,945.70	8,147.21
Tampa-St. Petersburg	53.68	77.13	344.78	1,801.71	0.18	1,115.39	9,684.64	2,003.64	3,917.91	3,014.03
Denver-Aurora	54.27	90.26	261.24	4,573.02	0.15	3,022.16	5,938.13	1,669.70	3,903.00	7,922.76
Milwaukee	50.52	249.81	499.15	4,909.77	0.21	3,703.17	19,385.12	1,302.36	3,953.59	7,380.29
Portland, OR	52.85	265.26	2,131.58	15,215.36	0.36	6,680.40	27,713.44	2,003.64	3,932.08	11,655.17
Providence-Fall River	56.00	370.77	1,013.84	9,344.83	0.39	3,365.68	32,617.34	2,337.58	3,949.62	8,621.98
Sacramento	53.10	70.41	167.51	4,274.48	0.07	1,327.79	1,707.41	2,671.52	3,919.40	5,988.51
Orlando	51.56	74.46	643.23	1,547.11	0.19	1,306.08	10,409.50	2,003.64	3,911.50	5,626.41
Louisville	47.31	67.04	690.19	4,734.00	0.17	927.02	11,284.19	2,003.64	3,926.08	3,927.41
Jacksonville	51.49	49.16	694.81	3,272.00	0.21	777.06	17,538.81	2,003.64	3,913.27	7,824.59
Bridgeport-Stamford	52.23	147.97	740.44	3,297.40	0.22	503.51	12,295.05	5,843.94	3,945.36	471.97
Richmond-Petersburg	52.07	134.44	963.63	1,339.26	0.29	1,280.58	24,014.27	1,502.73	3,923.98	3,450.70
Rochester, NY	56.01	131.08	853.04	11,790.97	0.25	1,813.31	20,205.08	2,671.52	3,953.63	8,515.70
Dayton	49.05	136.33	860.07	5,406.06	0.28	1,258.28	22,980.30	2,671.52	3,946.00	9,900.47
Austin	53.69	30.09	172.73	3,953.86	0.07	1,554.98	4,906.35	2,437.76	3,880.29	4,129.67
Albany	53.02	121.36	650.71	7,097.61	0.23	821.93	12,902.83	2,337.58	3,956.68	5,207.78
Albuquerque	48.62	101.16	537.06	4,252.94	0.18	1,449.16	11,174.73	1,669.70	3,912.72	9,271.74
Tulsa	52.18	163.12	1,234.07	10,047.15	0.38	1,177.17	24,869.66	2,671.52	3,937.78	5,693.98
Grand Rapids	50.76	113.96	816.63	1,766.65	0.28	1,294.32	15,449.62	3,573.15	3,935.95	8,000.92
Baton Rouge	45.90	190.07	592.74	6,952.74	0.23	1,571.18	15,213.41	1,669.70	3,934.03	7,881.90
Columbia, SC	49.37	205.91	968.83	4,521.89	0.34	1,987.02	38,795.69	1,669.70	3,934.06	2,987.51
Raleigh	50.42	45.23	443.07	12,381.51	0.15	1,437.99	9,095.34	2,003.64	3,890.61	2,009.32
Knoxville	50.91	69.76	291.19	5,144.25	0.12	842.80	7,279.10	1,669.70	3,929.34	4,145.70
Bakersfield	46.08	88.87	255.58	1,143.02	0.10	1,071.99	5,972.00	300.55	3,913.97	2,393.32
Des Moines	52.79	264.59	511.21	9,047.93	0.20	1,835.06	11,592.47	1,235.58	3,909.80	6,496.02
Spokane	50.45	283.06	621.34	6,539.49	0.25	1,347.39	15,053.23	1,669.70	3,932.58	10,521.59
McAllen	50.99	175.47	859.20	5,865.60	0.30	1,680.19	16,623.45	1,669.70	3,909.92	6,278.71
Ogden-Layton	46.84	106.35	336.33	7,473.35	0.17	1,419.77	10,860.56	1,602.91	3,924.14	8,116.49
Madison	48.10	125.23	482.77	7,560.59	0.19	657.76	11,474.92	2,337.58	3,939.07	3,680.65
Cape Coral	51.82	69.57	597.33	1,315.59	0.21	1,089.97	12,685.86	3,740.12	3,901.64	5,168.17
Lancaster, PA	51.22	256.99	782.65	5,920.07	0.31	2,131.75	17,839.17	1,669.70	3,941.18	7,989.12
Boise City	53.41	149.64	313.93	4,276.50	0.12	1,998.76	7,461.00	1,669.70	3,904.64	4,361.42
Salem, OR	49.15	288.35	783.76	1,637.20	0.27	1,721.31	17,804.97	6,344.85	3,927.01	11,899.29
Fort Collins	54.13	121.22	399.88	1,018.58	0.16	1,833.56	9,541.40	1,669.70	3,906.97	4,287.59
Totals ($US)	$51.77	$112.13	$175.56	$3,994.83	$0.13	$3,496.59	$2,461.67	$2,776.50	$3,923.36	$2,461.67

Endnotes

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[1] A "vehicle-mile of travel" (VMT) is defined as one vehicle traveling one mile, and is a common measure of transportation activity.

[2] Supreme Court of the United States, *Massachusetts et al. v. Environmental Protection Agency et al.* No. 05-1120. Argued November 29, 2006, Decided April 2, 2007, October Term, 2006, Available at: http://www.law.cornell.edu/suPercent /html/05-1120.ZO.html. The listed pollutants are carbon monoxide (CO), nitrous oxides (NO_x), sulfur dioxide (SO_2), particulate matter (Pm-2.5 and PM-10), lead (PB), and hydrocarbon (HC).

[3] The "corporate average fuel economy" (CAFE) is the sales-weighted average fuel efficiency, in MPG, that each motor vehicle manufacturer is required to achieve for each model year.

[4] Barack Obama, "State of California Request for Waiver Under 42 U.S.C. 7543(b), the Clean Air Act." Memorandum for the Administrator of the EPA, The White House, January 26, 2009. Available at: http://www.whitehouse.gov/the_press_office/Presidential_Memorandum_EPA_Waiver/

[5] Transportation Research Board, Annual Meeting Announcement, 2009 Annual Meeting, January 2009. Available at www.trb.org

[6] *AASHTO Journal*, "Climate Change and Energy Loom as Transportation Issues," February 29, 2008.

[7] South Coast Air Quality Management District Governing Board, 2007, *Final 2007 Air Quality Management Plan*, Los Angeles, CA: South Coast Air Quality Management District Governing Board.

[8] Proposed Senate Bill S.2191 would direct the EPA to establish a program for cutting greenhouse gas emissions while "preserving robust economic growth."

[9] Southern California Association of Governments, Los Angeles County Metropolitan Transportation Authority, Draft Long Range Transportation Plan for Los Angeles County, 2008.

[10] These estimates are somewhat lower than the estimates found in this assessment, possibly because of different regional definitions.

[11] Joanne R. Potter, et al., "Moving Cooler: How Effective Are Different Transportation Strategies in Reducing Greenhouse Gases?" Transportation Research Board Presentation, Session 745, January 14, 2009.

[12] Federal Highway Administration, Highway Performance Monitoring System, Urbanized Area Tables, reported in Highway Statistics, various years. Available at http://www.fhwa.dot.gov .

[13] David T. Hartgen, M. Gregory Fields and Claire G. Chadwick, *Are They Ready?* study for Urban Lane Institute, 2008, available at www.hartgengorup.net, and David T. Hartgen and M. Gregory Fields, *Congestion Reduction in Mid-sized Urban Regions* (Los Angeles: Reason Foundation, 2007-08). Available at www.hartgengroup.net.

[14] The "Travel Time Index" (TTI) is a widely used measure of regional congestion, defined as the travel time in the peak period compared with travel time in the off-peak.

[15] "High occupancy vehicle" (HOV) lanes are freeway lanes that are restricted to use by vehicles with 2+, or sometimes 3+, persons, and sometimes also motorcycles, buses and low-emission vehicles. "High occupancy toll" (HOT) lanes are lanes that restrict use to HOVs, *and* to single-person vehicles willing to

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pay a toll that may vary by time of day or congestion level. Other similar policies, such as full-lane or shoulder-lane congestion pricing, are not specifically analyzed here but results are likely to be similar in overall effect.

[16] If comparisons were made with the null forecast (new CAFE standards), most estimates would be lower in both absolute and relative terms. Therefore, this approach produces a likely maximum estimate of impact.

[17] Jon Creyts, Anton Derkach, Scott Nyquist, et al., 2007, *Reducing greenhouse gas emissions: how much at what cost?* A report by McKinsey & Company, p. ix. Available at: http://www.mckinsey.com/clientservice/ccsi/pdf/US_ghg_final_report.pdf.

[18] Kara Kockelman, Matthew Bomberg, Melissa Thompson, et al., 2008, *GHG Emissions Control Options: Opportunities for Conservation*, The National Academy of Sciences, Austin, TX: The University of Texas at Austin, p. 1. Available at: http://www.ce.utexas.edu/prof/kockelman/public_html/NAS_CarbonReductions.pdf.

[19] David T. Hartgen, M. Gregory Fields, Caleb A. Cox, et al., *Practical Congestion Relief for Mid-Sized Regions,* a report for Reason Foundation (Charlotte, NC: The Hartgen Group, Forthcoming 2009) and Hartgen, Fields and Chadwick, *Are They Ready?*.

[20] Los Angeles County Metropolitan Transportation Authority, Draft 2008 Long Range Transportation Plan for Los Angeles County, 2008. Available at http://www.metro.net/projects_studies/images/2008_draft_lrtp.pdf

[21] Genesee Transportation Council, *Long Range Transportation Plan for the Genesee-Finger Lakes Region: 2005 – 2025* (Rochester, NY: Genesee Transportation Council, 2004).

[22] Nicholas Schmidt and Michael Meyer, *Incorporating Climate Change Considerations into Transportation Planning,* Transportation Research Board 2009, Session 620, January 2009.

[23] Frank Gallivan, Jeffery Ang-Olson and Diane Turchetta, *Integrating Climate Change into State and Regional Transportation Plans,* Transportation Research Board 2009, Session 620, January 2009.

[24] ICF International, Integrating Climate Change into the Transportation Planning Process, A Report for the Federal Highway Administration (FHWA) (Washington, DC: FHWA, 2008).

[25] South Coast Air Quality Management District Governing Board, 2007, Final 2007 Air Quality Management Plan.

[26] Daniel B. Rathbone, "Transportation Emissions Reductions Strategies." *The Urban Transportation Monitor*, Vol. 22, No. 10, 2008, pp. 12-16.

[27] Stacy C. Davis and Susan W. Diegel, *Transportation Energy Data Book, Edition 26*, U.S. Department of Energy (DOE), Oak Ridge National Laboratory, Oak Ridge, TN, 2007, pp. 11-1 to 11-6. Available at http://cta.ornl.gov/data/tedb26/Edition26_Full_Doc.pdf.

[28] National Energy Information Center (NEIC), 2004, *Greenhouse Gases, Climate Change, and Energy,* Washington, DC: Energy Information Administration. Available at: http://www.eia.doe.gov/oiaf/1605/ggccebro/chapter1.html.

[29] World emissions data are from 2005; U.S. data from 2006. Since both have increased since 2005, it is likely that U.S. percentages are slightly overstated. Energy calculations based on Energy Information Administration (EIA), 2008, *International Energy Outlook 2008*, [prepared under the general direction of John Conti and Glen E. Sweetnam], US Department of Energy, Washington, DC, Table A-10. Transportation calculations made using data from the *Transportation Energy Data Book 27*, Tables 11-1, 11-5 and 11-6. Stacy C. Davis, Susan W. Diegel, and Robert G. Boundy, 2008, *Transportation Energy Data Book, Edition 27*, U.S. Department of Energy (DOE), Oak Ridge National Laboratory, Oak Ridge, TN.

[30] Energy Information Administration (EIA), 2008, *International Energy Outlook 2008*.

[31] Percent increases are calculated using 2005 as a base, but percent decreases use 2030 as a base. A 51.8% increase between 2005 and 2030 is equivalent to a 34.2% decrease from 2030 to 2005.

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[32] This is a very conservative assumption, as consumer demand in response to high gas prices, combined with technological innovation, would likely increase fuel efficiency of vehicles in the absence of CAFE standards.

[33] Federal Highway Administration, HPMS tabulations of VMT by region, vehicle class and functional class supplied by Tom Roff, October 2008.

[34] Since truck shares are slowly increasing on the higher systems, this assumption may understate CO_2 emissions slightly.

[35] Peak-hour proportions are slowly declining in most regions but the peak periods are spreading out, so these effects compensate for each other.

[36] *Transportation Energy Data Book*, 2008 Ed. 27, calculated from summary data, p. 4-1 and p. 5-1.

[37] Gasoline 0.008798 metric tons of CO_2 emissions per gallon; diesel 0.010068 metric tons of CO_2 emissions per gallon. Source: EPA, Office of Transportation and Air Quality, "Emission Facts," Feb 2005, available at: http://www.epa.gov/otaq/climate/420f05001.pdf.

[38] Edward L. Glaeser and Matthew Kahn, "The Greenness of Cities," John F. Kennedy School of Government, Harvard University, March 2008. Available at: http://www.hks.harvard.edu/rappaport/downloads/policybriefs/greencities_final.pdf

[39] Because forecasts of vehicle shares by functional class and type are slightly different than in 2005, the percent increases in VMT, fuel use and CO_2 are not identical.

[40] National travel estimates through 2008 were 3.6% below 2007. Source: FHWA, Traffic Volume Trends. Available at www.fhwa.dot.gov.

[41] 2009 VMT was 0.2 % higher than 2008. Source: Federal Highway Administration, Traffic Volume Trends, December 2009.

[42] Energy Policy and Conservation Act, 1975, as described in the *Transportation Energy Data Book*, 2007, p. 4-18.

[43] For the 2007 Model Year, the standard was 27.5 MPG, but the actual sales-weighted CAFE was 31.0 MPG, *Transportation Energy Data Book*, 2007, p. 4-18.

[44] Highway Statistics, Federal Highway Administration, 1993 and 2006.

[45] U.S. Congress, Energy Independence and Security Act of 2007 Public Law 110-140, Title I, Subtitle A, Section 102, available at http://www.senate.gov/reference/active_bill_type/110.shtml#E

[46] California Law AB 1493 (Pavley), 2002.

[47] California Air Resources Board, "Comparison of Greenhouse Gas Reductions for the U.S. and Canada under U.S. CAFE Standards and CARB GHG Regulations," Feb. 25, 2008. Available at: http://www.arb.ca.gov/cc/ccms/ccms.htm.

[48] S. Power, "Obama's EPA Move Likely to Spur Fight," *The Wall Street Journal*, January 27, 2009.

[49] Of the 48 regions studied here, 46 forecast significant improvement in air pollution from listed pollutants.

[50] This calculation does not account for variations in speeds, which are discussed in later chapters.

[51] U.S. Congress, Title 49 U.S.C.A, Section 32902, "Average Fuel Economy Standards," January 2, 2006, available at : http://www4.law.cornell.edu/uscode/49/usc_sec_49_00032902----000-.html

[52] Energy Information Administration, "Analysis of Corporate Average Fuel Economy (CAFE) Standards for Light Trucks and Increased Alternative Fuel Use", March 2002. Available at: http://www.eia.doe.gov/oiaf/servicerpt/cafe/index.html

[53] Congressional Budget Office, "The Economic Costs of Fuel Economy Standards Versus a Gasoline Tax," December 2003, Available at http://www.cbo.gov/ftpdocs/49xx/doc4917/12-24-03_CAFE.pdf ; Congressional Budget Office, "Reducing Gasoline Consumption: Three Policy Options," The Congress of the United States, November 2002. Available at: https://www.cbo.gov/doc.cfm?index=3991&type=0

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[54] National Highway Traffic and Safety Administration, "Corporate Average Fuel Economy for MY 2011-2015 Passenger Cars and Light Trucks," April 2008, Available at: http://www.nhtsa.gov/staticfiles/DOT/NHTSA/Rulemaking/Rules/Associated%20Files/CAFE_2008_PRIA.pdf

[55] 15,000, 35,000, and 90,000 miles per year, for passenger cars and light trucks, single-unit commercial trucks and combination trucks, respectively.

[56] "The short-run rebound effect is simply the elasticity of VMT with respect to CPM. The long-run rebound effect is the short-run effect divided by one minus the coefficient estimate on the first order lag of VMT." See W. Maximilian Auffhammer, Michael Hanemann, Sarah Szambelan, "Managing Greenhouse Gas Emissions in California, Chapter 8: Transportation, Section 3.2," The California Climate Change Center at UC Berkeley, January 2006, Available at: http://calclimate.berkeley.edu/managing_GHGs_in_CA.html, http://calclimate.berkeley.edu/8_Transportation.pdf, p. 8-20 to 8-27.

[57] National Highway Traffic and Safety Administration, "Corporate Average Fuel Economy for MY 2011-2015 Passenger Cars and Light Trucks," April 2008, Available at: http://www.nhtsa.gov/staticfiles/DOT/NHTSA/Rulemaking/Rules/Associated%20Files/CAFE_2008_PRIA.pdf, p. VIII-5-VIII-8, VIII-11.

[58] Ibid., VIII-8.

[59] Auffhammer, et al., "Managing Greenhouse Gas Emissions in California," p. 8-20 to 8-27.

[60] Kenneth Small and Kurt Van Dender, "The Effect of Improved Fuel Economy on Vehicle Miles Traveled: Estimating the Rebound Effect Using State Data, 1996-2001," September 2005, University of California Energy Institute. Available at: www.ucei.org. Also, K Small and K Van Dender, "Fuel efficiency and Motor Vehicle Travel: the Declining Rebound Effect," *Energy Journal*, 28:1, 2007.

[61] Based on an assumed 45 MPG (33.1 on-the road) by 2030 for passenger cars and light trucks, 13.43 on-the-road MPG for single-combination trucks, and 8.35 on-the-road MPG for combination trucks.

[62] Todd Litman, "Efficient Vehicles versus Efficient Transportation: Comparing Transportation Energy Conservation Strategies," Victoria Transport Policy Institute, May 6, 2005. Available at: http://www.vtpi.org/cafe.pdf

[63] Victoria Transportation Policy Institute, Online Transportation Demand Management (TDM) Encyclopedia, 2004, Available at www.vtpi.org

[64] Federal Highway Administration, Highway Statistics, 2006, Urbanized Area tables. At www.fhwa.dot.gov

[65] S.M. Chin, O. Franzese, D.L. Greene, H.L. Hwang and R.C. Gibson, *Temporary Losses of Highway Capacity and Impacts on Performance: Phase 2 (TLC2)*, Prepared for the U.S. Department of Energy, (Oak Ridge, TN: Oak Ridge National Laboratory, October 2004), p. 67.

[66] Ibid, p. 68.

[67] Matthew Barth, and Kanok Boriboonsomsin, 2008, "Real-World CO_2 Impacts of Traffic Congestion," Paper for the 87th Annual Meeting of Transportation Research Board, Washington, D.C., p. 10.

[68] Ibid, p. 10.

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[69] Chin, et al., *Temporary Losses of Highway Capacity and Impacts on Performance: Phase 2 (TLC2)*, p. 68.

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[135] National Transit Cooperative Research Program, "Public transportation's role in addressing climate change," *Research Results Digest 89*, March 2009.

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a higher portion of weekday VMT would be to/from work. Backing out children's trips, 35% is a reasonable, but probably high, estimate of the portion of weekday VMT that is work-related.

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