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Opportunities to Reduce Greenhouse Gas Emissions through Transportation Reauthorization and Energy Policy

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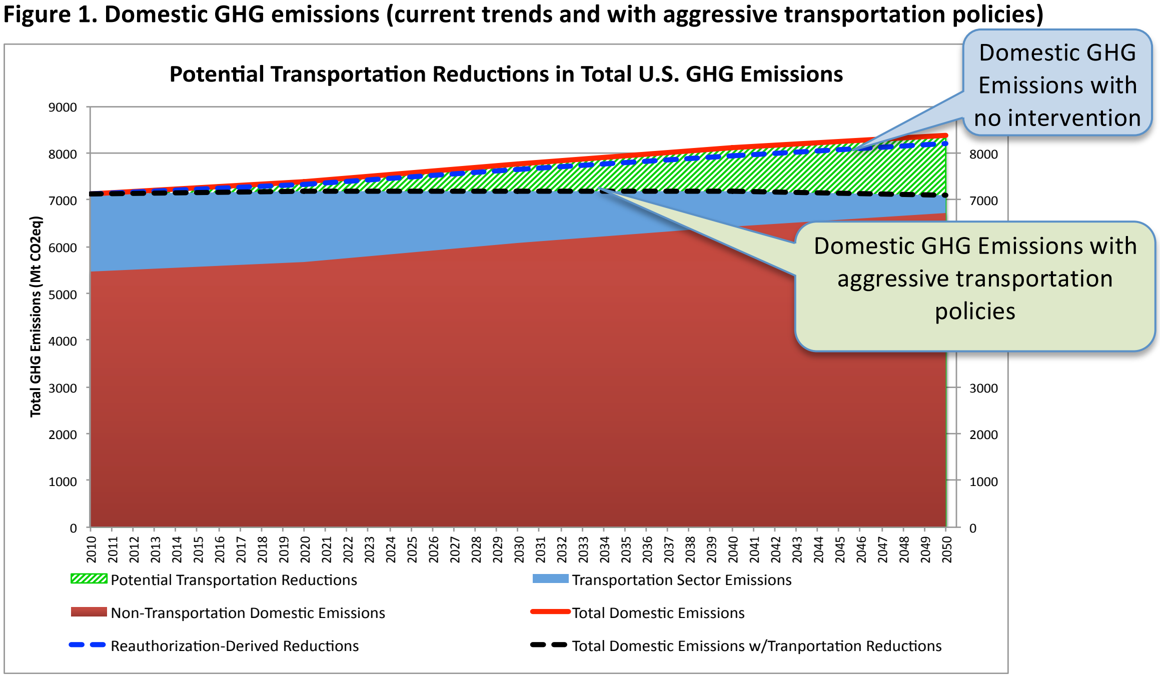
KEY POINTS

- An aggressive application of transportation sector policies could reduce cumulative emissions by 2050 by 36% and annual GHG emissions from transportation by about 12% by 2020, 35% by 2030, and 77% by 2050. Annual GHG emissions in 2050 could be as much as 77% lower than 2010 emissions. Policies would need to address transportation demand, vehicle fuel efficiency, and the types of fuels used.
- The effect on total domestic GHG emissions would be notable. Transportation sector policies could reduce domestic emissions by about 2.9% by 2020 and slightly more than 15% by 2050. This is enough to stabilize total U.S. GHG emissions. (Figure 1 shows this potential effect.)
- Policies that fall within the scope of the federal surface transportation reauthorization law could reduce transportation sector emissions by up to 3.4% by 2020, increasing to 6.9% by 2030, and reaching 10.5% by 2050. This would require a moderately aggressive application of policies that reduce overall travel, change land use patterns, reduce delays and improve transportation operations, encourage alternative modes, and reduce the speed limit.

Figure 1. Domestic GHG emissions (current trends and with aggressive transportation policies)



- These reductions can potentially be achieved without imposing higher net costs on consumers for transportation activity. The cumulative economic effect from 2012 to 2050 (not including time-related savings) from applying sector-wide policies would be a net benefit to transportation system users of about \$2.6 trillion (-\$106/ton[1]). Cost estimates are highly dependent on underlying assumptions; with higher estimated costs, the cumulative abatement cost by 2050 could be as high as \$6.1 trillion (\$254/ton). Better data and modeling are needed to narrow this range in potential economic effects.
- Individual transportation policies also have significant uncertainty about abatement costs, and estimated costs for each policy vary widely. The expected cost to abate one ton of transportation sector GHG emissions ranges from −\$650 to \$5,000; using higher cost assumptions, the range is

[1] The term *ton* (abbreviated *t*) in this paper refers to the metric ton (1 ton [or *tonne*] = 1,000 kg = 2,204.62 lbs.). Hence, the abbreviation *Mt* refers to the megaton (1 million metric tons)

−$400 to $7,000. (Table 3 shows this range of potential abatement costs.) These variations in costs for different policies mean that the mix of policies can significantly affect the overall cost and effectiveness of any multi-faceted strategy to reduce transportation sector GHG emissions.

BACKGROUND

The U.S. transportation sector accounts for about 28% of total domestic greenhouse gas (GHG) emissions, 34% of carbon dioxide emissions, and 68% of domestic oil consumption.[2] It is also the fastest-growing source of domestic GHG emissions.[3] Emissions from surface transportation activity—travel on roads and by rail—account for about 80% of total transportation GHG emissions.[4]

Transportation is an important part of the current policymaking agenda in the United States. Congress is faced with passing a major surface transportation authorization bill that establishes programs and spending levels for surface transportation (road and rail), revenue sources, and planning requirements for the next five to six years. The previous bill expired in 2009, and there is significant pressure on Congress to complete the reauthorization bill. Although not as prominent an issue as during the past few years, climate change concerns are still a relevant part of transportation policy discussions, and the role of policies to reduce GHG emissions continues to be a significant interest for many policy makers.

This paper summarizes the potential for GHG reductions from policies that would influence the transportation sector. It also presents and discusses the expected costs for individual strategies and shows how combined policies might distribute emissions reductions and costs between individual policies. Three main transportation "policy wedges" are considered:

- Policies that would be addressed through the federal surface transportation reauthorization bill. These primarily affect the level of travel demand and the efficiency of the transportation system.
- Policies that improve vehicle efficiency. These are typically considered as part of comprehensive energy policy.
- Policies that change the amount of carbon in transportation fuels. These are usually part of comprehensive energy policy or agriculture policy.

With surface transportation reauthorization pending in Congress, individual strategies within the travel demand policy wedge are identified and discussed in more detail.

Aggregate potential for transportation emissions reductions

With an aggressive implementation of policies that reduce travel demand, increase vehicle fuel efficiency, and reduce the carbon content of fuels, transportation emissions could be reduced 12.4% by 2020, increasing to 77.5% by 2050. These three strategies can be thought of as "policy wedges" that each have a maximum potential for reduced transportation GHG emissions. The individual potential for each of these policy "wedges" is shown in Table 1 and Figure 2, below. These estimates of emissions reduction potential were assembled from a variety of recent studies and reports.[5] These reports all show significant

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[2] Stacey Davis, et al., *Transportation Energy Data Book, Volume 29* (Oak Ridge, TN: Oak Ridge National Laboratory, U.S. Department of Energy, 2010), http://cta.ornl.gov/data/index.shtml.
[3] U.S. Environmental Protection Agency, "Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1998–2008," U.S. EPA # 430-R-10-006 (Washington, D.C.: U.S. EPA, 2010), http://www.epa.gov/climatechange/emissions/usginv_archive.html.
[4] U.S. Department of Energy, "Annual Energy Outlook 2011," Report Number: DOE/EIA-0383(2011) (Washington, D.C.: U.S. Department of Energy, April 2011), http://www.eia.gov/forecasts/aeo/pdf/0383(2011).pdf.
[5] Primary sources include U.S. Department of Transportation, "Report to Congress: Transportation's Role in Reducing Greenhouse Gas Emissions" (2010); David Greene and S. Plotkin, "Reducing Greenhouse Gas Emissions from U.S. Transportation" (Pew Center on Global Climate Change, 2011); Cambridge Systematics, "Moving Cooler" (Urban Land Institute, 2009); Lewison Lem, "Greenhouse Gas Emissions Reduction Potential and Associated Costs from Transportation and Land Use Strategies for 50 States," presentation to Institute for Transportation Studies (University of California at Davis, 2010);

variation and uncertainty in emissions reductions and abatement costs. To present more clear analysis, this paper uses single values for abatement potential and costs that were selected from the range of values in the source reports; Tables 1a and 2a show these ranges and the selected values.

Figure 2. Transportation sector GHG reduction potential from combined policies

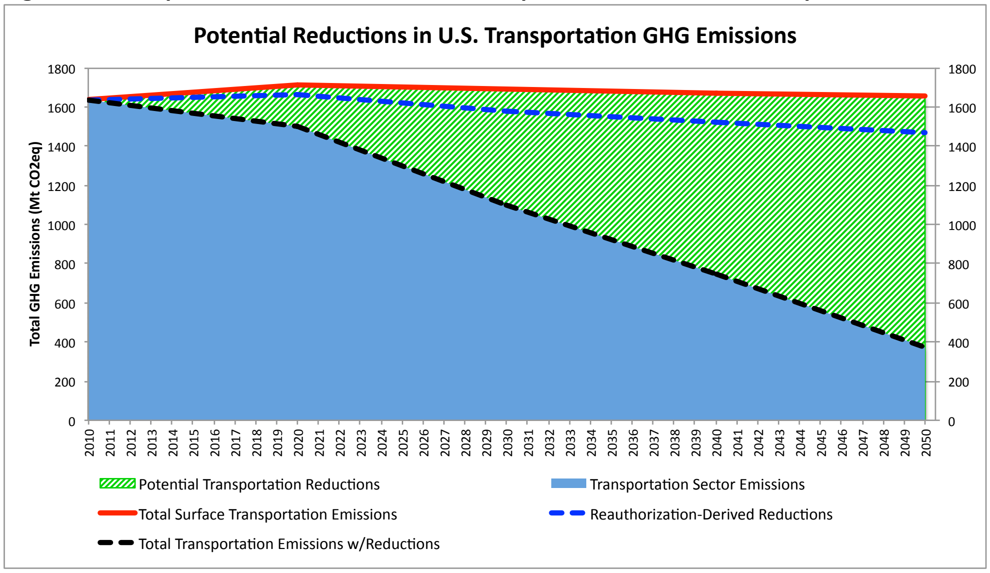


Table 1. Long-term emissions reduction potential from available policy tools (2020–2050)[6]

	2020	2030	2040	2050
Projected Baseline Emissions (Mt)	*1,712*	*1,689*	*1,671*	*1,653*
Potential **Combined Reauthorization Effect**[7] **(percent of baseline emissions)**	***58.6*** (3.4%)	***116.7*** (6.9%)	***143.9*** (8.6%)	***173.6*** (10.5%)
REDUCED VEHICLE ENERGY CONSUMPTION **(percent of baseline emissions)**	***68.5*** (4.0%)	***337.8*** (20.0%)	***551.4*** (33.0%)	***694.3*** (42.0%)
REDUCED FUEL ENERGY INTENSITY **(percent of baseline emissions)**	***85.6*** (5.0%)	***135.2*** (8.0%)	***225.6*** (13.5%)	***413.3*** (25.0%)
***POTENTIAL* COMBINED REDUCTIONS (Mt)** **(percent of baseline emissions)**	**212.7** (12.4%)	**589.7** (34.9%)	**920.9** (55.1%)	**1,281.2** (77.5%)

and U.S. Environmental Protection Agency, "A Wedge Analysis of the U.S. Transportation Sector" (2007). See Appendix A for details of sources and estimates.

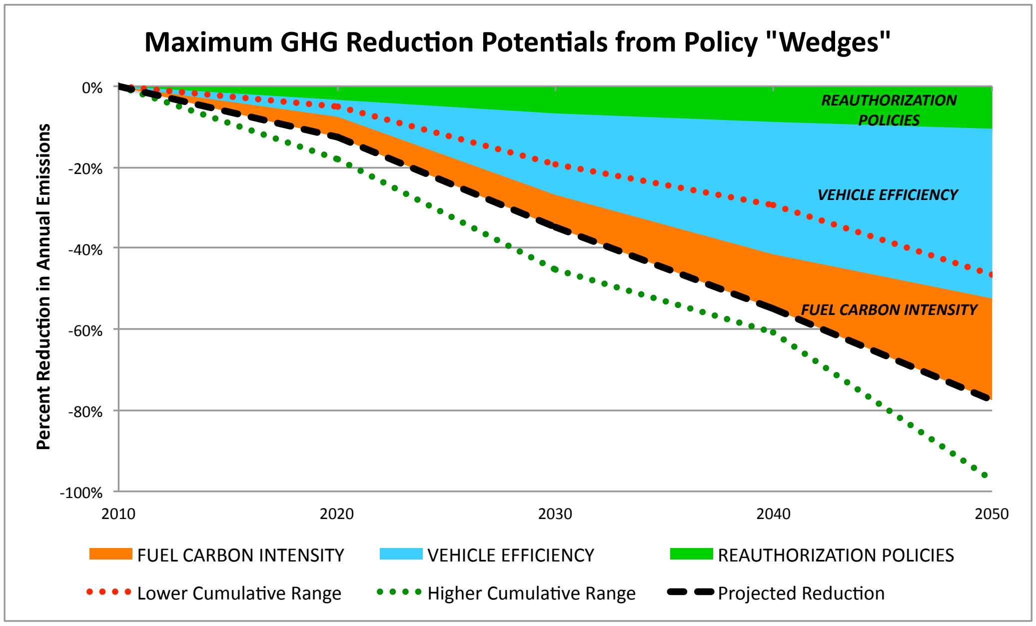
[6] These are estimates of the cumulative potential from a moderately aggressive implementation of policies that could be included as part of reauthorization *and* policies that are typically from another legislative vehicle, such as energy-related or agriculture legislation. Estimates are derived from the author's analysis of a variety of sources, including sources from footnote 5 above. (See Appendix A.)

[7] Potential combined reauthorization-related policies are 70% of the additive effects from these policies. This reduction factor is applied to approximate expected interactions of the different policies. More research on the interactions of policies to reduce transportation GHG emissions is needed to provide policy makers with the most effective understanding of expected effects from combined policies.

Table 1a. Emissions reduction potential ranges and selected values (2020–2050)

	2020	2030	2040	2050
Projected Baseline Emissions (Mt)	*1,712*	*1,689*	*1,671*	*1,653*
Potential **Combined Reauthorization Effect**[6]	***58.6***	***116.7***	***143.9***	***173.6***
(expected range)	(34.2–120.2)	(70.3–171.4)	(92.4–210.6)	(109.9–251.1)
REDUCED VEHICLE ENERGY CONSUMPTION	***68.5***	***337.8***	***551.4***	***694.3***
(expected range)	(17.1–102.7)	(16.9–422.3)	(334.2–551.4)	(495.9–727.3)
REDUCED FUEL ENERGY INTENSITY	***85.6***	***135.2***	***225.6***	***413.3***
(expected range)	(34.2–85.6)	(84.5–168.9)	(66.8–250.7)	(165.3–628.1)
POTENTIAL **COMBINED REDUCTIONS (Mt)**	**212.7**	**589.7**	**920.9**	**1,281.2**
(expected range)	(85.5–308.5)	(171.7–762.6)	(493.4–1012.7)	(771.1–1606.5)

Figure 3. Transportation's major policy wedges (percent of baseline)



Each of these policy wedges reduces overall transportation emissions, but they do so in different ways. The potential effects of the policy wedges are additive, so that each can have an effect on emissions, but the maximum potential is reached when policies are combined. The effectiveness of each of these policy wedges is measured as the emissions reductions they might achieve. Interactions between policies are not estimated for this paper, but would certainly occur.[8] The "aggregate" approach used for this paper is based on the potential for individual strategies described in Appendix A, but the effects are not completely additive; to incorporate potential interactions between policies, estimates for combinations of

[8] Other analytical approaches allow policies to be considered by the effects they have on contributing factors to transportation GHG emissions. For example, the "KAYA identity"—described in Greene and Plotkin, ibid.—measures travel demand policy effectiveness by how much the policy reduces vehicle miles traveled, vehicle fuel efficiency as reductions in per-mile fuel use, and fuel carbon intensity as reductions in per-gallon CO_2 emissions. These components can then be multiplied by each other to estimate the total GHG emissions reduction. This type of analytical approach allows policies to be developed and analyzed based on their component effects and interactions, rather than just by the expected effect on emissions. For simplicity, this paper uses the aggregate measure, which simply establishes the emissions reduction potential without breaking down component factors; a separate Nicholas Institute policy brief in production presents a component-based analytical approach using projections of U.S. trends.

reauthorization-related strategies were reduced by 30% from their individual potentials. Sources that were used to estimate potential from the vehicle and fuels policy wedges generally incorporated interaction effects into their estimates of reduction potential, so no adjustment of these aggregate values was needed.

This paper primarily discusses policies that could be implemented as part of surface transportation reauthorization. Combining potential reauthorization-related policies might reduce transportation GHG emissions by 3.4% by 2020, 6.9% by 2030, 8.6% by 2040, and 10.5% by 2050. Improvements to vehicle fuel economy and carbon content of fuels fall largely outside the traditional realm of reauthorization. They are, however, promising strategies: improving vehicle fuel economy could reduce transportation GHG emissions by 4% by 2020, increasing to 42% by 2050; reducing the carbon content of fuels could reduce emissions by 5% in 2020, increasing to 25% by 2050.

The overall amount of travel activity—for both passengers and freight—is the primary factor that leads to transportation GHG emissions. Vehicle fuel efficiency and the carbon content of fuel affect only travel that actually occurs, so avoided or shortened trips can have a major effect. Yet there are significant concerns about the linkage between economic activity and travel: travel occurs primarily to allow access to economic or social activity. Understandably, most policy makers are probably hesitant to enact policies that potentially reduce economic activity. But travel can be reduced without limiting access to desired or needed activities by encouraging mode shifts, trip-chaining, more compact land use patterns, etc.[9] These types of policies are typically addressed through the federal surface transportation authorization process.

Vehicle fuel efficiency improvements can be the result of increased fuel economy standards (miles per gallon, through Corporate Average Fuel Economy requirements), tailpipe emissions limits (lbs. or grams of GHG emissions per mile), or indirect policies that promote more efficient vehicle technologies, like tax breaks for hybrid or electric vehicles. The most significant limitation of strategies that increase vehicle fuel efficiency is that gains can be wiped out by more travel: a 10% increase in fuel economy would be wiped out by a 10% increase in VMT. Travel can increase either as a result of general economic demand, or as a result of a "rebound effect," where lower per-mile fuel costs of travel result in slight increases in travel activity.

The amount of carbon in overall consumed transportation fuels—called "carbon intensity"—can be modified with a number of policy tools, including policies that require a minimum amount of alternative fuels as part of the overall fuel mix of fuels ("Renewable Fuels Standards"), or general requirements that transportation fuel providers limit the carbon intensity of the fuel they sell (Low-Carbon Fuel Standard), but without mandating which alternatives are used. These types of policies must overcome barriers related to existing refueling infrastructure, uncertain costs for alternative fuels and general economics for fuel sellers, and consumer acceptance of alternative fuels.

[9] Conceptually, the goal of these policies is to reduce travel without limiting access to economic or social activity. Those activities provide consumers with utility. Potential ways to evaluate and address utility and travel demand will be explored in the forthcoming Institute policy brief mentioned in footnote 8.

EMISSIONS REDUCTION POTENTIAL FOR INDIVIDUAL REAUTHORIZATION POLICIES

As Congress prepares to address reauthorization of the federal surface transportation law, the potential GHG reductions that can be achieved by different reauthorization-related strategies can be informative. Table 2 and Figure 4 show these potential reductions.

Table 2. Long-term emissions reduction potential from available reauthorization policy tools[10]

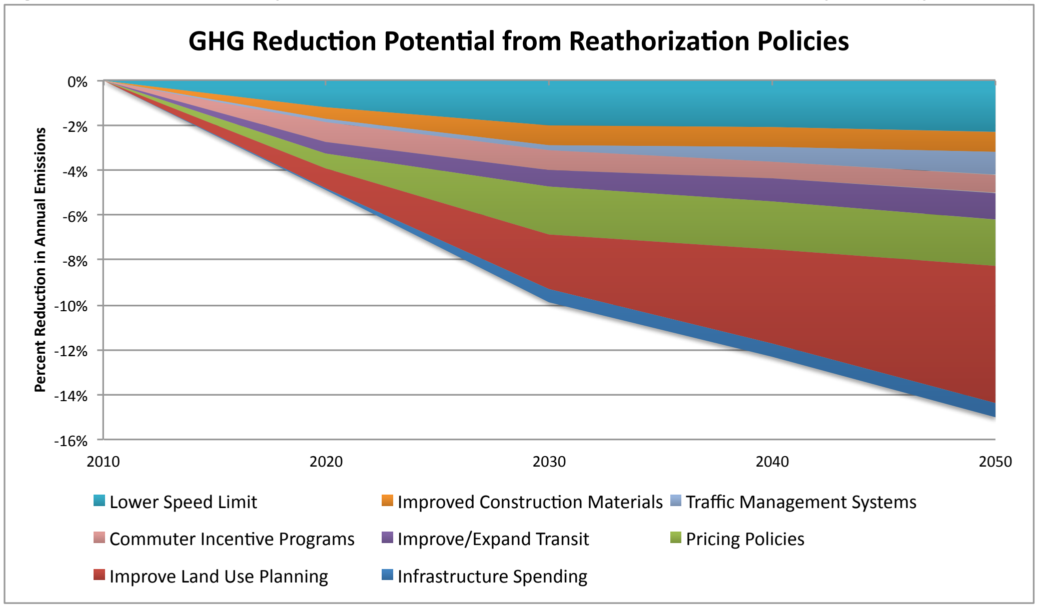
REAUTHORIZATION POLICY COMPONENTS	2020	2030	2040	2050
Projected baseline emissions (Mt)	*1,712*	*1,689*	*1,671*	*1,653*
Infrastructure Spending (+$15B/year)	1.0	10.0	10.0	10.0
Improve land use planning	15.6	41.2	70.0	100.0
Pricing policies	11.0	35.0	35.0	35.0
Improve/expand transit	8.6	13.5	16.7	20.0
Lower speed limit	20.5	33.0	35.5	38.0
Improved construction materials	9.0	15.0	15.0	15.0
Traffic management systems	3.0	4.8	9.9	16.5
Commuter incentive programs	15.0	14.2	13.5	13.5
TOTAL	58.6	116.7	143.9	173.6

Table 2a. Potential abatement range and selected values from reauthorization policy tools

REAUTHORIZATION POLICY COMPONENTS	2020	2030	2040	2050
Projected baseline emissions (Mt)	*1,712*	*1,689*	*1,671*	*1,653*
Infrastructure spending (+$15B/year)	**1.0**	**10.0**	**10.0**	**10.0**
Expected Range	(1.0–3.1)	(5.0–10.0)	(5.0–10.0)	(5.0–10.0)
Improve land use planning	**15.0**	**40.0**	**70.0**	**100.0**
Expected Range	(6.9–59.9)	(16.9–67.6)	(33.4–108.6)	(49.6–148.8)
Pricing policies	**11.0**	**35.0**	**35.0**	**35.0**
Expected Range	(8.6–22.3)	(20.3–47.3)	(21.7–45.1)	(23.1–41.3)
Improve/expand transit	**8.6**	**13.5**	**16.7**	**19.8**
Expected Range	(5.1–17.2)	(6.8–16.9)	(10.0–20.1)	(9.9–26.5)
Lower speed limit	**20.5**	**33.0**	**35.5**	**38.0**
Expected Range	(13.7–39.4)	(27.0–42.2)	(30.1–53.5)	(33.1–66.1)
Improved construction materials	**9.0**	**15.0**	**15.0**	**15.0**
Expected Range	(3.4–10.3)	(11.8–18.6)	(11.7–18.4)	(11.6–18.2)
Traffic management systems	**3.0**	**4.0**	**10.0**	**16.0**
Expected Range	(1.7–4.3)	(4.1–25.3)	(10.0–26.7)	(13.2–26.5)
Commuter incentive programs	**15.0**	**14.0**	**13.5**	**13.0**
Expected Range	(8.6–15.4)	(8.5–16.9)	(10.0–18.4)	(1.6–21.5)
TOTAL (Mt)	**58.6**	**116.7**	**143.9**	**173.6**
Expected Range	(34.2–120.2)	(70.3–171.4)	(92.4–210.6)	(109.9–251.1)

[10] These are estimates of the potential from a moderately aggressive implementation of policies that could be included as part of reauthorization. Estimates are derived from the author's analysis of the same sources identified in footnote 5.

Figure 4. GHG reduction potential from individual reauthorization-related policies (percent)



Specific reauthorization-related policies generally include infrastructure spending (which is the topic of a companion Nicholas Institute Policy Brief); improving land use, transportation, and transit planning; policies that price travel on a per-mile basis, like congestion pricing, pay-as-you-drive insurance, and VMT fees; expanding transit service and improving the quality of transit; employer-based programs to reduce commuters' travel; technical improvements to the transportation system and operations; selecting materials for construction and maintenance that have lower life-cycle emissions; and lowering the speed limit to reduce fuel consumption. This paper does not recommend any specific policies, but presents them to facilitate policy analysis and considerations of how different policies have different reduction potentials and costs.

GHG ABATEMENT COSTS VARY SIGNIFICANTLY

Because policies that can reduce GHG emissions and energy consumption have different potential results and expected costs, an understanding of these expected results and costs is needed to develop and compare policy alternatives. Table 3 shows the expected costs for each policy wedge and individual strategy to reduce GHG emissions by one ton ("abatement costs"). Both expected abatement costs and high abatement cost values are presented in Table 3; these cost estimates were developed by reviewing recent reports and studies that include both abatement potential and costs. A wide range of costs exists in the literature—see Tables A-3 and A-4 in Appendix A—so approximate midpoint abatement costs were selected as the "expected" values. Because there is considerable uncertainty and variety in these estimates, a higher-cost estimate was also selected. All costs presented in Table 3 represent approximate average abatement costs based on the cumulative abatement potential through 2050.[11]

[11] Only abatement values over a long period of time (roughly 2012–2050) are used to help alleviate methodological limitations with using single abatement costs for technical and interrelated policies. These limitations and the need for better cost-related research and estimates are described below.

Table 3. Cumulative GHG abatement potential and per-ton costs for transportation policy tools

TRANSPORTATION POLICY COMPONENTS	Cumulative abatement potential	Abatement cost+ (expected cost)	Abatement cost+ (high estimate)
Projected Baseline Emissions (Mt)	*67,706*	*Dollar/ton*	*Dollar/ton*
Infrastructure spending (+$15B/year)	185	$5000	$7000
Improve land use planning	1,267	-$650	-$400
Pricing policies	698	-$375	$10
Improve/expand transit	346	$700	$1,000
Lower speed limit	762	-$310	-$200
Improved construction materials	328	$450	$650
Traffic management systems	186	$50	$120
Commuter incentive programs	346	-$650	-$300
COMBINED TRAVEL DEMAND POTENTIAL[12]	***4,118***	Varies	Varies
REDUCED VEHICLE ENERGY CONSUMPTION	***13,361***	-$200	$200
REDUCED FUEL ENERGY INTENSITY	***6,694***	$50	$350
TOTAL COMBINED REDUCTIONS (Mt)	**24,173**	Varies	Varies

+ Abatement costs presented here were developed from a variety of sources; more accurate abatement costs would vary with the level of actual GHG abatement and over time. The need for better cost-related information in future policy analyses is described below.

A key point from Table 3 is that many policies can achieve reductions in transportation GHG emissions with negative expected abatement costs, i.e., implementing those policies will reduce costs. Previous research has also estimated negative costs for transportation GHG abatement policies, with one report concluding that "reducing carbon emissions from passenger vehicles may result in very large net benefits (excluding the climate benefits), rather than large costs, when noncarbon externalities [e.g., traffic congestion—*author*] … are taken into account."[13] Others have emphasized the inherent challenges and risks of relying on single abatement costs for policy development, emphasizing that abatement cost estimates can be highly dependent on a number of key assumptions about technologies, underlying costs, path dependency and the timing of new technologies, and how to simplify complex systems and decision-making processes.[14] With higher abatement costs, fewer policies would have negative costs. The abatement costs are shown graphically in Figures 5 and 6, and the relative efficiencies and costs of reductions form the basis for subsequent comparative analyses of policy combinations.

Figure 4 presents average abatement costs (from 2012 to 2050) for transportation policies (individual reauthorization-related policies are shown, but overlaid by the average for these travel demand policies). This type of chart is useful for evaluating the relative merits of different policies. The width of each

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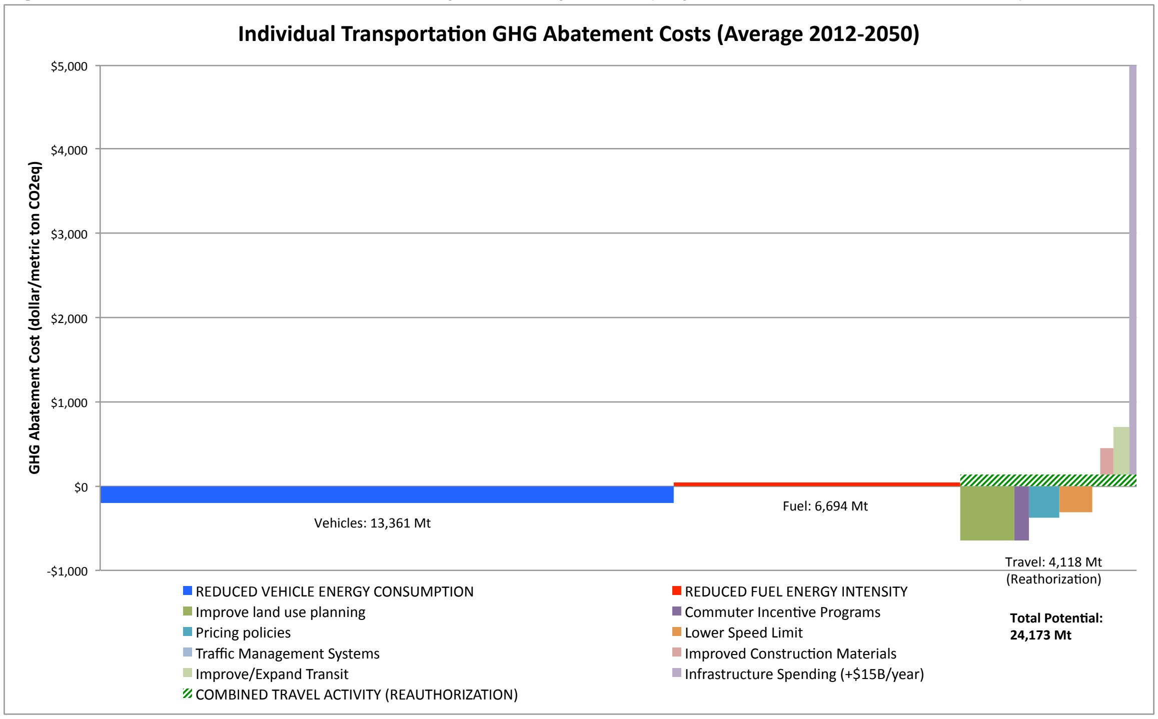
[12] Potential combined reauthorization-related policies are 70% of the additive effects from these policies. This reduction factor is applied to approximate expected interactions of the different policies. More research on the interactions of policies to reduce transportation GHG emissions is needed to provide policy makers with the most effective understanding of expected effects from combined policies.

[13] Ian W.H. Parry, "Are the Costs of Reducing Greenhouse Gases from Passenger Vehicles Negative?" *Journal of Urban Economics* 62 (2007): 273–293.

[14] See, for example, Paul Ekins, F. Kesicki, and A. Smith, "Marginal Abatement Cost Curves: A Call for Caution," report commissioned by Greenpeace U.K. (London: University College of London, April 2011), https://www.ucl.ac.uk/energy/home-top-cols/image-link-docs/MACCCritGPUKFin.pdf. This paper includes an extensive discussion of the validity threats to simplified abatement cost estimates. It also includes an example of how an estimated abatement cost for a vehicle technology—in this case hybrid drivetrains—can be highly sensitive to assumptions about the vehicle cost, fuel efficiency, or lifetime; small changes in these assumptions can swing the abatement cost from a negative one to a cost of hundreds of dollars per ton. This paper bolsters both the need for caution in over-reliance on abatement cost estimates and the need for improving these estimates.

column shows the emissions reduction potential for each strategy, and the column height shows the cost per ton. (Charts showing only reauthorization-related policies are shown in Appendix B.)

Figure 5. GHG abatement costs for transportation policies (expected "low" abatement costs)



Figures 5–7 are ***not abatement cost curves*** *for either the entire transportation sector or these individual policy tools*; a comprehensive policy would probably distribute emissions reductions across all potential strategies, rather than start only with the lowest-cost alternatives. The next section discusses how costs can be considered for different levels of policy implementation.

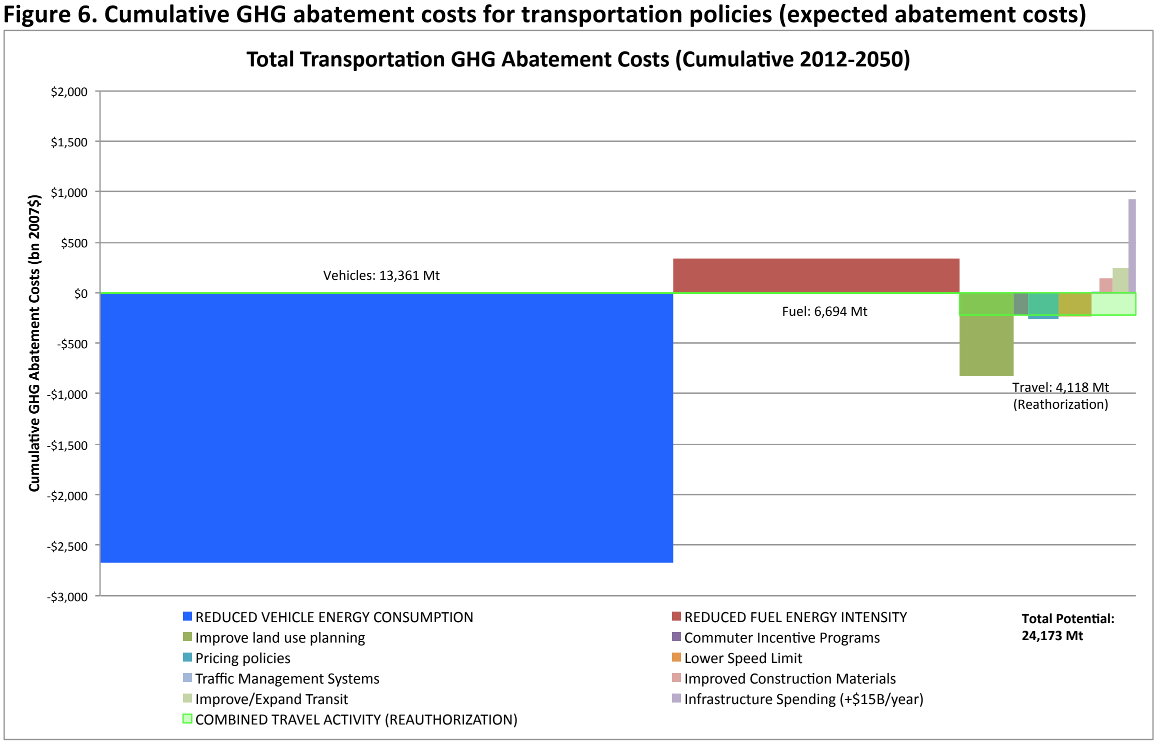
Cumulative abatements and cost totals through 2050 are presented in Table 4 and in Figures 6 (low expected abatement costs) and 7 (high abatement costs). These are the total transportation-related implementation and monetary costs or benefits for each potential strategy from 2012 to 2050. The chart shows that the combined cumulative benefits and costs for all strategies would be a net benefit: if these transportation strategies were implemented to their maximum emission-reducing potential, they would generate a substantial net economic benefit for transportation system users. (Charts showing reauthorization-only policies are presented in Appendix B.)

Table 4. Maximum achievable cumulative GHG abatement potential and cumulative costs

TRANSPORTATION POLICY COMPONENTS	Cumulative abatement potential	Cumulative cost+ (expected cost)	Cumulative cost+ (high estimate)
Projected baseline emissions (Mt)	*67,706*	*Billion 2007$*	*Billion 2007$*
Infrastructure spending (+$15B/year)	185	$926	$1,296
Improve land use planning	1,267	-$824	-$507
Pricing policies	698	-$262	$7
Improve/expand transit	346	$242	$346
Lower speed limit	762	-$236	-$152
Improved construction materials	328	$147	$213
Traffic management systems	186	$9	$22
Commuter incentive programs	346	-$225	-$104
***COMBINED TRAVEL DEMAND POTENTIAL*[15]**	***4,118***	***-$222***	***$1,121***
REDUCED VEHICLE ENERGY CONSUMPTION	***13,361***	***-$2,675***	***$2,672***
REDUCED FUEL ENERGY INTENSITY	***6,694***	***$335***	***$2,343***
TOTAL COMBINED REDUCTIONS (Mt)	**24,173**	**-$2,559**	**$6,136**

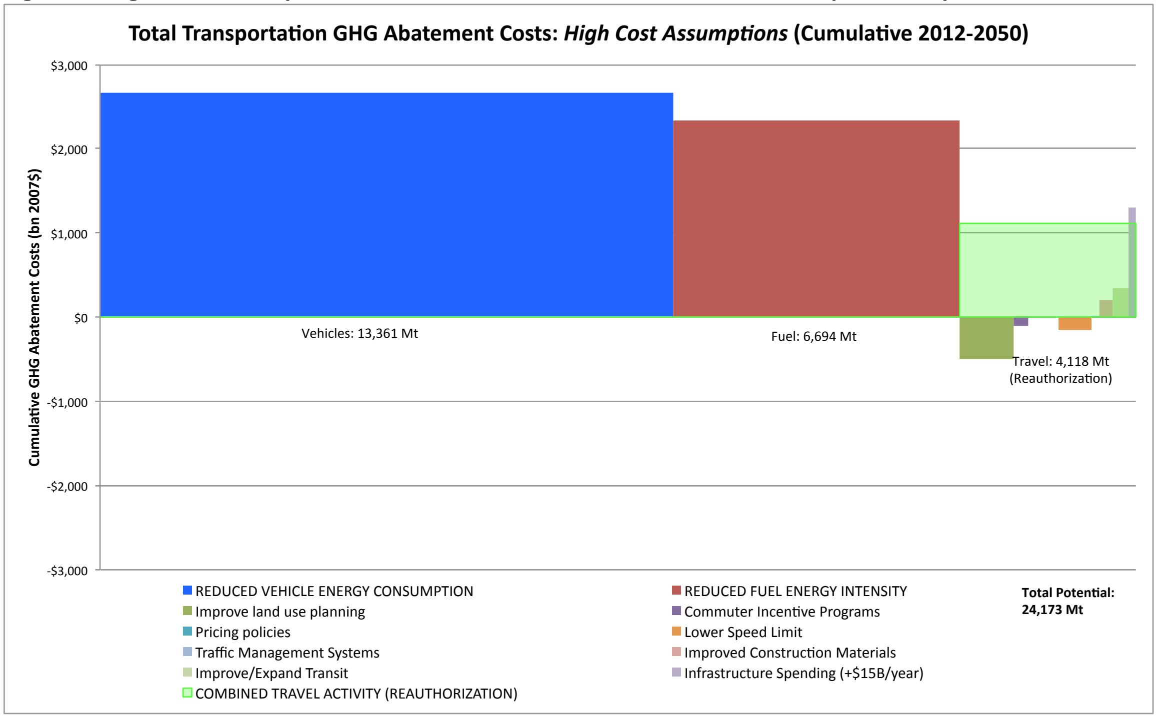
+ Abatement costs presented here were developed from a variety of sources; more accurate abatement costs would vary with the level of actual GHG abatement and over time. The need for better cost-related information in future policy analyses is described elsewhere.

Figure 6. Cumulative GHG abatement costs for transportation policies (expected abatement costs)



[15] Potential combined reauthorization-related policies are 70% of the additive effects from these policies. This reduction factor is applied to approximate expected interactions of the different policies. More research on the interactions of policies to reduce transportation GHG emissions is needed to provide policy makers with the most effective understanding of expected effects from combined policies.

Figure 7. High-cost assumptions cumulative GHG abatement costs for transportation policies



As mentioned earlier, a number of strategies allow abatement to occur at a net savings, but the scale of these potential cumulative savings can be seen in Figure 6. For example, using the expected abatement costs, the potential cumulative savings that could be achieved by improving vehicle efficiency total about $2.7 trillion dollars by 2050; all other policies combined would cost a total of about $113 billion. (With the higher estimated abatement costs in Table 3 and Figure 7, full vehicle efficiency abatement would cost nearly $2.7 trillion, and other policies combined would cost about $3.5 trillion.) Because all policies discussed here achieve long-term emissions reductions, it would be possible to develop policy combinations to share costs or benefits and overall GHG emissions reductions from different policies and across a variety of segments of the transportation community, and still achieve net savings.

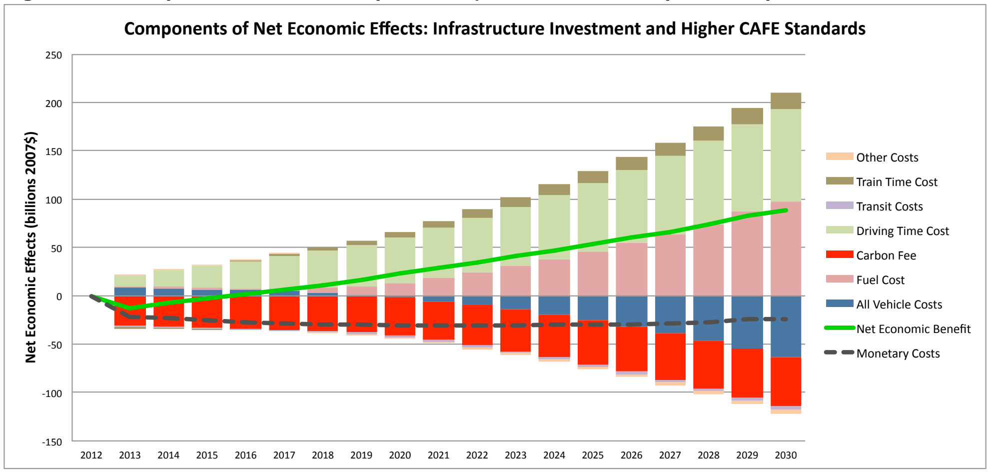
Better data about abatement costs would improve analysis

The studies and reports used as source material for this paper report abatement costs for different policies (see Appendix A, Tables A-3, A-4, and A-5), but those figures are inconsistently developed and vary by the year they report. Generally, only the direct monetary costs relating to implementing a policy (e.g., the costs of building necessary infrastructure, the vehicle cost increases needed to increase fuel efficiency) and the costs or benefits from operating a vehicle after a policy has been implemented (e.g., the lower maintenance costs after new infrastructure has been developed, the reduced per-mile fuel costs after new fuel economy standards are implemented) are used for the calculations. A more complete evaluation of these strategies should include cost information that also reflects how time-related costs change; earlier work has shown that time savings for transportation-related policies can be very significant. Figure 8 is an example from a previous report showing the various cost components of a policy.[16] In this example

[16] The specific policy analyzed here involves implementing a carbon fee and then reinvesting a portion of the revenue into infrastructure improvements. See Craig Raborn, "Transportation Infrastructure Spending and Climate Outcomes: Effects of Reinvesting Transportation Carbon Fee Revenues in Transportation Infrastructure," Working Paper NI WP 10-05 (Durham, NC: Nicholas Institute for Environmental Policy Solutions, Duke University, December 2010), http://nicholasinstitute.duke.edu/climate/lowcarbontech/transportation-infrastructure-spending-and-climate-outcomes for more information.

(shown for illustrative purposes), which includes infrastructure improvements, a carbon fee, and an annual 4% increase in vehicle fuel efficiency, time-related costs constitute about 30% of the total economic effect (and about 50% of the economic benefits); fuel savings constitute a similarly sized effect.

Figure 8. Transportation cost components (illustrative example from previous Institute report)[17]



The changes over time in abatement costs for different strategies also need more research. Abatement costs for this report are presented as a single per-ton cost. But the abatement costs for most policies will change as the amount of abatement changes, or over time. It is possible that for some policies, abating 10 million tons may cost more per ton than abating 7 million tons, and for other policies abatement might cost. Similarly, as a new policy is implemented and becomes more established over time, the associated abatement costs may decrease.

An improved understanding of the economic effects associated with transportation policies would provide policy makers with better tools to develop and evaluate alternatives. Existing reports are not deficient because developing accurate estimates of economic effects from policies requires extensive modeling and analysis, yet there is a need to better understand the costs associated with policies that affect the transportation sector. Because economic effects should be considered as part of the policy development process, developing accurate estimates should also be a priority for researchers and analysts. The Nicholas Institute's SIMTRAVE model, which uses economic factors and costs to estimate travel activity and responses for passenger and freight modes to different policy options, could be used to improve abatement cost estimates.

POLICY COMBINATIONS AND COSTS: COMPARATIVE EXAMPLES

The potential for distributing GHG reductions and economic costs across policies and segments of the transportation community is shown below. Three sample strategies that achieve 25% of the potential annual reductions in GHG emissions using different policy mixes are developed. These strategy combinations are described below:

- "Equal Policy Wedges": reduces emissions equally from the three main "policy wedges" (travel demand, vehicle efficiency, and fuel intensity)
- "Lowest Costs Preferred": reduces emissions by 10% for all policies, but achieves the remaining 15% by preferring strategies with lower abatement costs

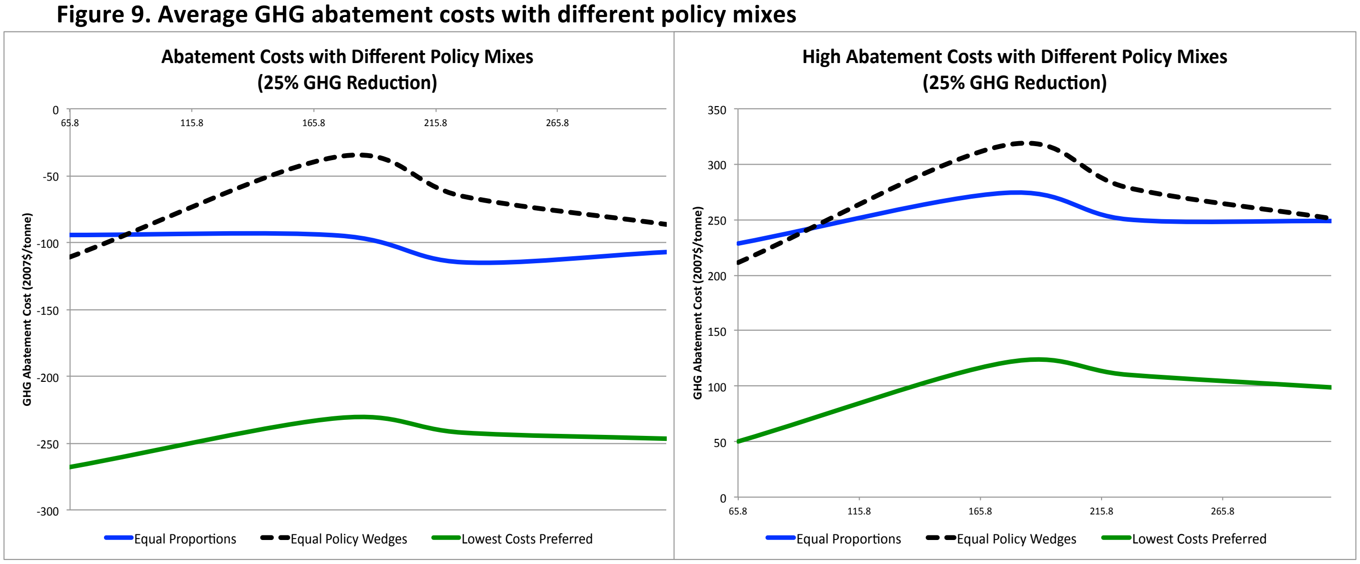
[17] See Raborn, 2010, ibid.

- "Equal Proportions": reduces emissions equally by 25% across the board for all individual policies and policy wedges

Only monetary costs associated with the policy implementation or transportation operations are included in these abatement costs; the value of time saved by travel—which might be significant for many of the travel demand strategies[18]—were not calculated as part of most of the reports from which these costs are derived.[19]

Costs to reduce GHG emissions can vary depending on the specific mix of policies: Figure 7 shows the abatement costs for these three different policy mixes, each of which reduces transportation GHG emissions by 25%. The policy mix that reduces emissions equally across all available policies has the highest potential abatement costs, but the mixture of strategies still achieves abatement with a net economic benefit (see Tables 5 to 7 for abatements and costs for each policy in these mixes). Because many transportation policies can reduce emissions without imposing actual economic costs, the "equal proportions" policy mix also achieves many GHG emissions reductions as net benefits. The other two policies each reduce transportation GHG emissions without imposing net costs. A comprehensive policy set that achieves some emissions reductions from each individual strategy, but increases reductions from policies that have higher net savings, provides the greatest benefits in conjunction with emissions reductions. A policy that reduces emissions equally across each "policy wedge" (travel demand, fuel efficiency, and fuel carbon content) also provides net benefits.

Figure 9. Average GHG abatement costs with different policy mixes



[18] For example, see Craig Raborn, "Transportation and Climate Policy Summary: Greenhouse Gas Emissions Resulting from Different Infrastructure Spending Levels," Policy Brief NI PB 11-03 (Durham, NC: Nicholas Institute for Environmental Policy Solutions, Duke University, June 2011), http://nicholasinstitute.duke.edu/climate/policydesign/greenhouse-gas-emissions-resulting-from-infrastructure-spending-levels. Economic benefits from time savings (e.g., reduced congestion delays, shorter transit stop waiting times) reported in those—and other—studies have been in the billions of dollars per year for policies that increase infrastructure spending and improve traffic capacity or conditions.

[19] The emissions reductions and cost effects used in this report are from a variety of sources (see footnote 5). The Nicholas Institute operates SIMTRAVE, a transportation sector model that also estimates time-related costs and savings from different strategies. The purpose of this paper is summarize and contextualize potential emissions reductions from pre-existing sources; future Nicholas Institute reports will utilize SIMTRAVE to also provide the time-related economic effects of strategies.

Policy mixes have different costs and abatements

These three sample policy combinations also show two important points:

1. The same levels of GHG emissions reductions can be achieved through different combinations of policies, and
2. Different combinations of policies will achieve their abatement with different overall costs.

The following detailed results from the sample policy combinations show these patterns. Generally, these results show how the levels of abated GHG emissions can vary significantly for individual policies, while the total abatement for each combination is approximately the same. This pattern can be seen in the results of cumulative abatement from 2050 in Table 5, which shows how the scenarios can achieve roughly the same abatement, but with substantially different sources of abatement. To attain an overall abatement of 25% of the potential maximum abatement, some policies might need to achieve as much as 64% of their potential, while some might not achieve more than 10%. From a climate policy perspective—focused on reducing GHG regardless of the source—this potential distribution of reduction burden to achieve an abatement target may not be a significant policy driver. From the transportation sector perspective, however, the policies needed to achieve these types of distributions of emissions reductions might also affect important policy drivers such as congestion relief, job creation, and supporting economic development. With the variety of abatement potential from different policies, the potential to target policies for both emissions reduction and to meet transportation-related goals can be explored by policy makers and stakeholders.

Similarly, abatement costs at the level of individual policies vary widely between the sample policy combinations, but because abatement costs can be both negative and positive, the cumulative costs for these policies can vary widely. Tables 6 and 7 show the estimated low and high cumulative abatement costs for the three scenarios. Rather than focus on the calculated abatement costs—which are subject to significant uncertainty (see previous discussion on costs)—the notable cost-related trend is the large variety in costs for abatement from different policies. Although not explored in this paper, different policies would also affect different stakeholders or populations, so the variety of abatement costs indicates that policy combinations that achieve equal GHG emissions abatement might affect populations or stakeholders in significantly different ways. This point should be further explored so that policy makers can better understand the full impacts of potential alternatives.

Results from scenarios: 2012 to 2050 cumulative

Table 5. Different policy mixes achieve 25% GHG reductions (2050, cumulative)

Strategy element	Potential reduction	"Equal wedges"	"Lowest costs"	"Equal proportions"
Baseline projection	(67,706 Mt)	(67,706 Mt)	(67,706 Mt)	(67,706 Mt)
Infrastructure spending (+$15B/year)	185.2	92.7	18.5	46.3
Improve land use planning	1267.1	652.2	805.6	316.8
Pricing policies	697.9	339.5	421.2	174.5
Improve/expand transit	345.6	167.1	34.6	86.4
Lower speed limit	762.1	361.6	440.1	190.5
Improved construction materials	327.6	154.1	32.8	81.9
Traffic management systems	186.4	96.4	18.6	46.6
Commuter incentive programs	345.6	154.5	210.4	86.4
REAUTHORIZATION STRATEGIES (combined)*	4117.5	2018.0	1981.7	1029.4
VEHICLE FUEL EFFICIENCY	13361.4	2020.0	3398.1	3340.4
FUEL CARBON INTENSITY	6694.4	2018.0	669.4	1673.6
TOTAL	24,173.3	6,056.0	6,049.2	6,043.4

* Potential combined reauthorization-related policies are 70% of the additive effects from these policies. This reduction factor is applied to approximate expected interactions of the different policies. More research on the interactions of policies to reduce transportation GHG emissions is needed to provide policy makers with the most effective understanding of expected effects from combined policies.

Table 6. Cumulative abatement costs to achieve 25% potential GHG reductions (expected abatement costs)

Strategy element	"Equal wedges"	"Lowest costs"	"Equal proportions"
Reauthorization strategies	*$ billion*		
Infrastructure spending (+$15b/year)	$463.7	$92.6	$231.4
Improve land use planning	($424.0)	($523.6)	($205.9)
Pricing policies	($127.3)	($158.0)	($65.4)
Improve/expand transit	$116.9	$24.2	$60.5
Lower speed limit	($112.1)	($136.4)	($59.1)
Improved construction materials	$69.3	$14.7	$36.9
Traffic management systems	$4.8	$0.9	$2.3
Commuter incentive programs	($100.4)	($136.8)	($56.2)
REAUTHORIZATION STRATEGIES (combined)*	($109.0)	($822.3)	($55.5)
VEHICLE FUEL EFFICIENCY	($404.0)	($679.6)	($668.1)
FUEL CARBON INTENSITY	$100.9	$33.5	$83.7
TOTAL	($412.1)	($1,468.5)	($639.9)

Table 7. Cumulative abatement costs to achieve 25% potential GHG reductions (high abatement costs)

Strategy element	"Equal wedges"	"Lowest costs"	"Equal proportions"
REAUTHORIZATION STRATEGIES	*$ billion*		
Infrastructure spending (+$15b/year)	$649.1	$129.6	$324.0
Improve land use planning	($260.9)	($322.2)	($126.7)
Pricing policies	$3.4	$4.2	$1.8
Improve/expand transit	$167.1	$34.6	$86.4
Lower speed limit	($72.3)	($88.0)	($38.1)
Improved construction materials	$100.1	$21.3	$53.2
Traffic management systems	$11.6	$2.2	$5.6
Commuter incentive programs	($46.4)	($63.1)	($25.9)
REAUTHORIZATION STRATEGIES (combined)*	$551.7	($281.5)	$280.2
VEHICLE FUEL EFFICIENCY	$404.0	$679.6	$688.1
FUEL CARBON INTENSITY	$706.3	$234.3	$585.8
TOTAL	$1,662.0	$632.5	$1,534.1

Figures 10–16 graphically present the comparative estimated and high cumulative abatement cost data in Tables 5–7; although the abatement costs shown are estimates, the figures show how similar levels of GHG abatement can be achieved with widely different costs. Figure 10 shows the cumulative GHG abatement and abatement costs for each policy wedge for the three scenarios. The expected abatement costs and higher estimated costs are presented as side-by-side figures, so that the relative differences in cost can be seen. The figures on the left side use the expected (i.e., lower-range) abatement costs, while the comparison figures on the right side use the higher estimated range of abatement costs. Figures 11–16 show the detail for reauthorization-related policies for the three scenarios, in pairs with the expected abatement costs and higher-range costs. The GHG abatement for each policy in these paired figures is the same, but the costs are significantly different. Again, the abatement costs—both expected and high—are estimated from a range of literature sources and are intended to show the maximum range of potential abatement costs based on current literature; a more comprehensive set of estimated abatement costs could help narrow the range of potential values.

Figure 10. Comparison between policy mixes and abatement cost assumptions

Expected (medium) abatement costs | *High estimated abatement costs*

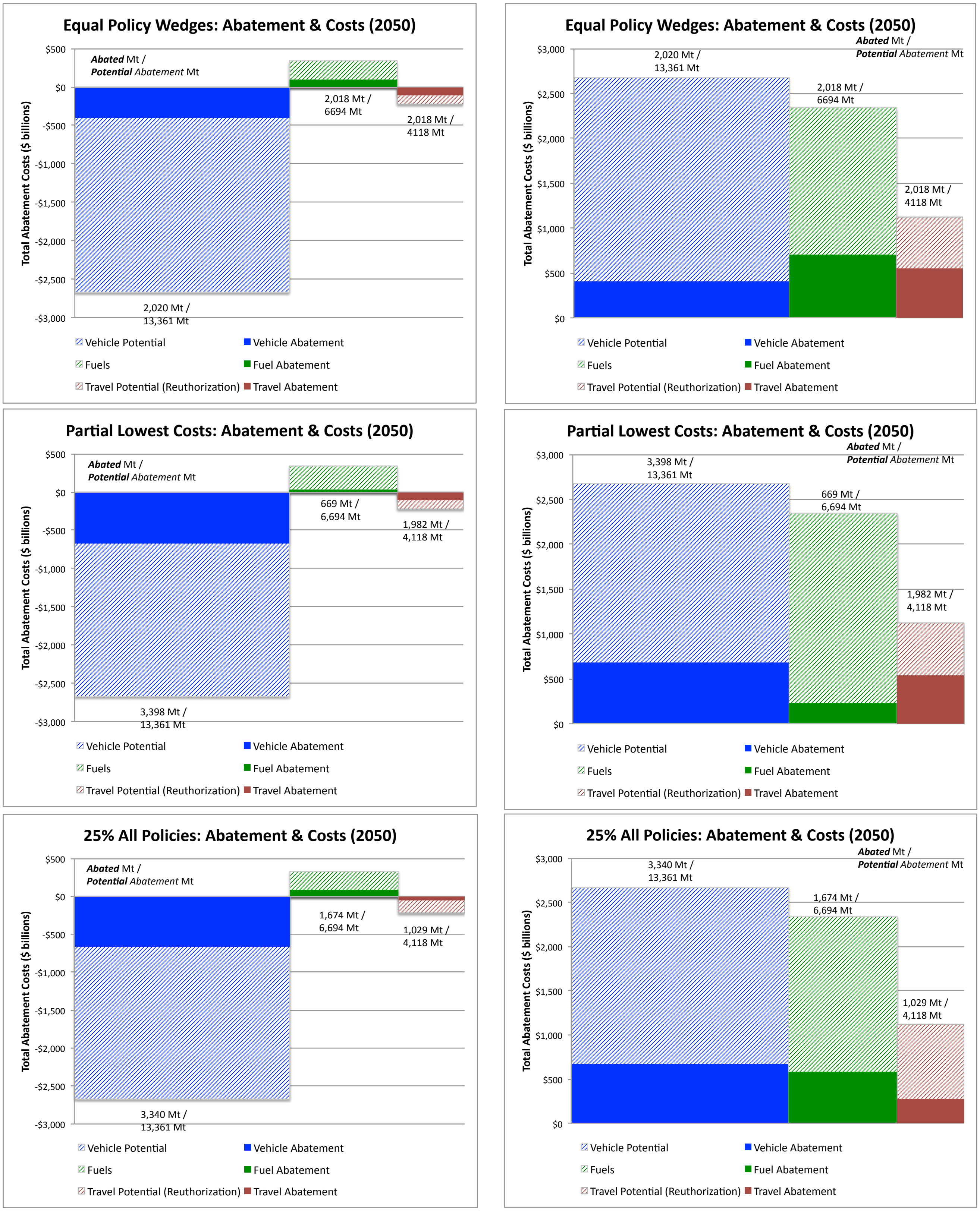


Figure 11. Equal policy wedges, cumulative expected abatement costs (reauthorization policies)

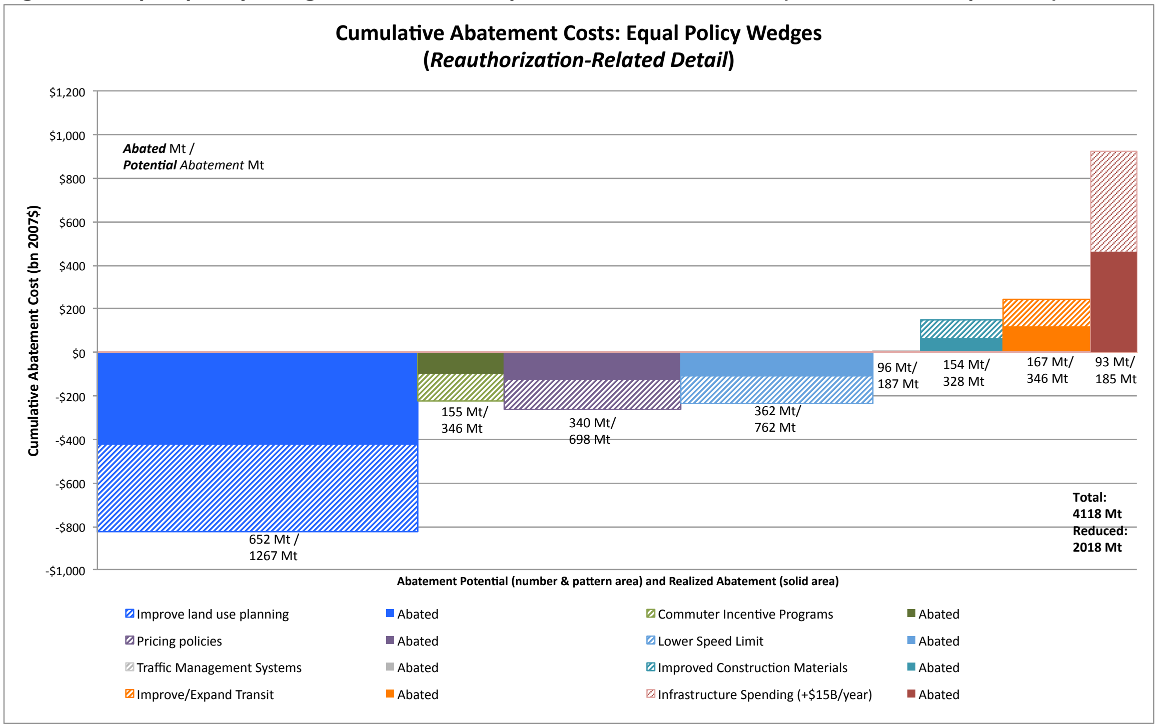


Figure 12. Equal policy wedges, cumulative high abatement costs (reauthorization policies)

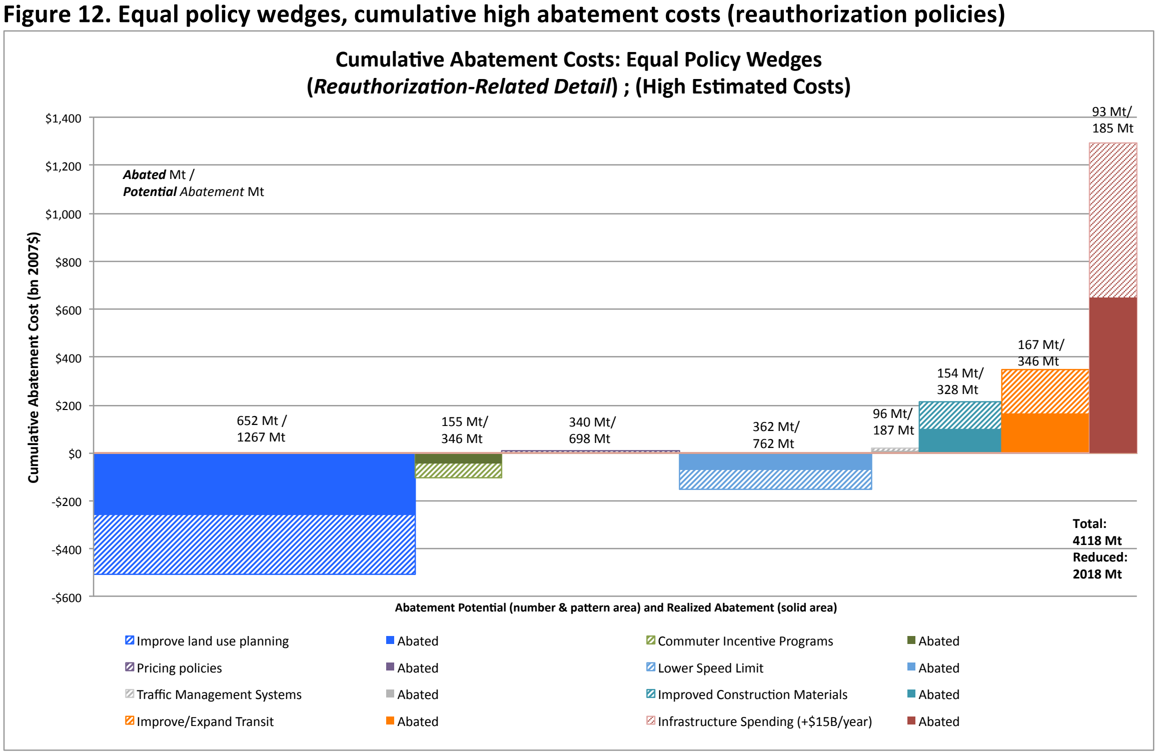


Figure 13. Lowest-cost, cumulative expected abatement costs (reauthorization policies)

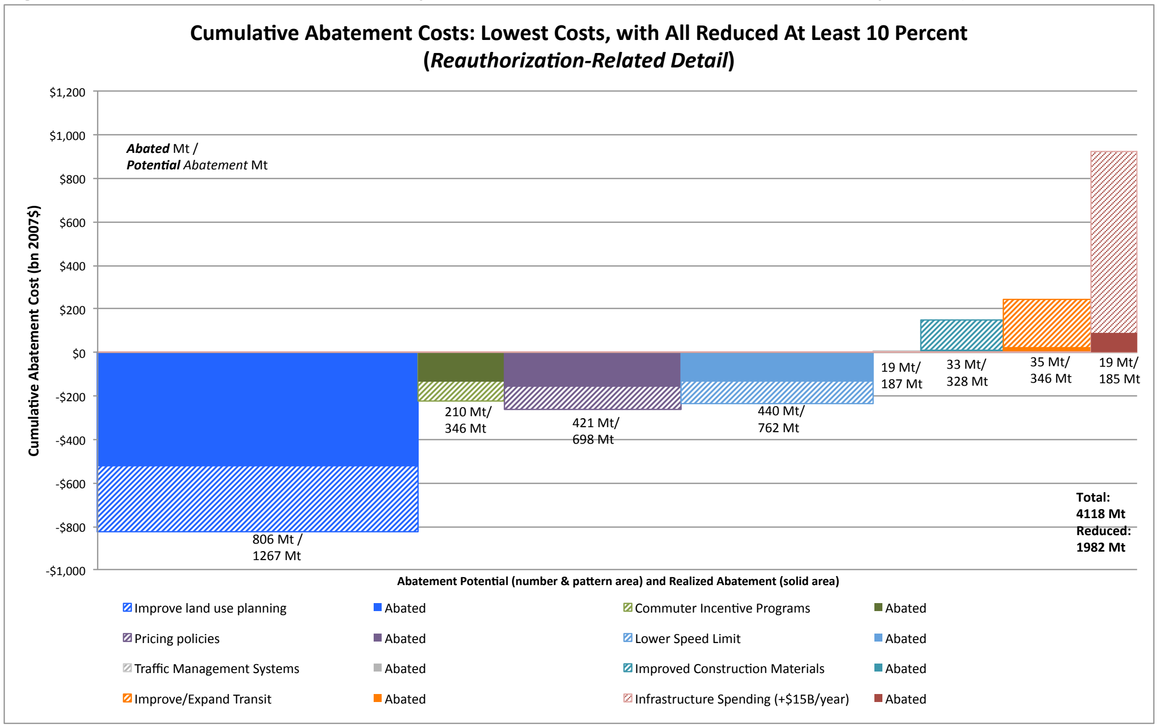


Figure 14. Lowest-cost, cumulative high abatement costs (reauthorization policies)

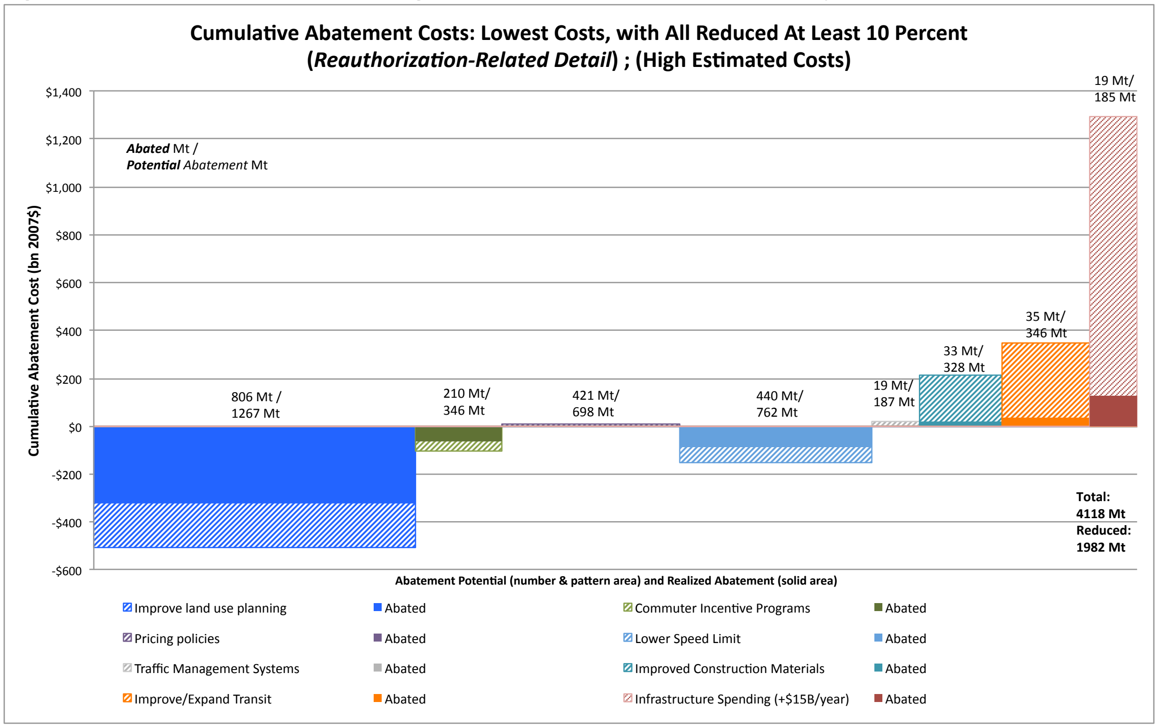


Figure 15. All policies 25%, cumulative expected abatement costs (reauthorization policies)

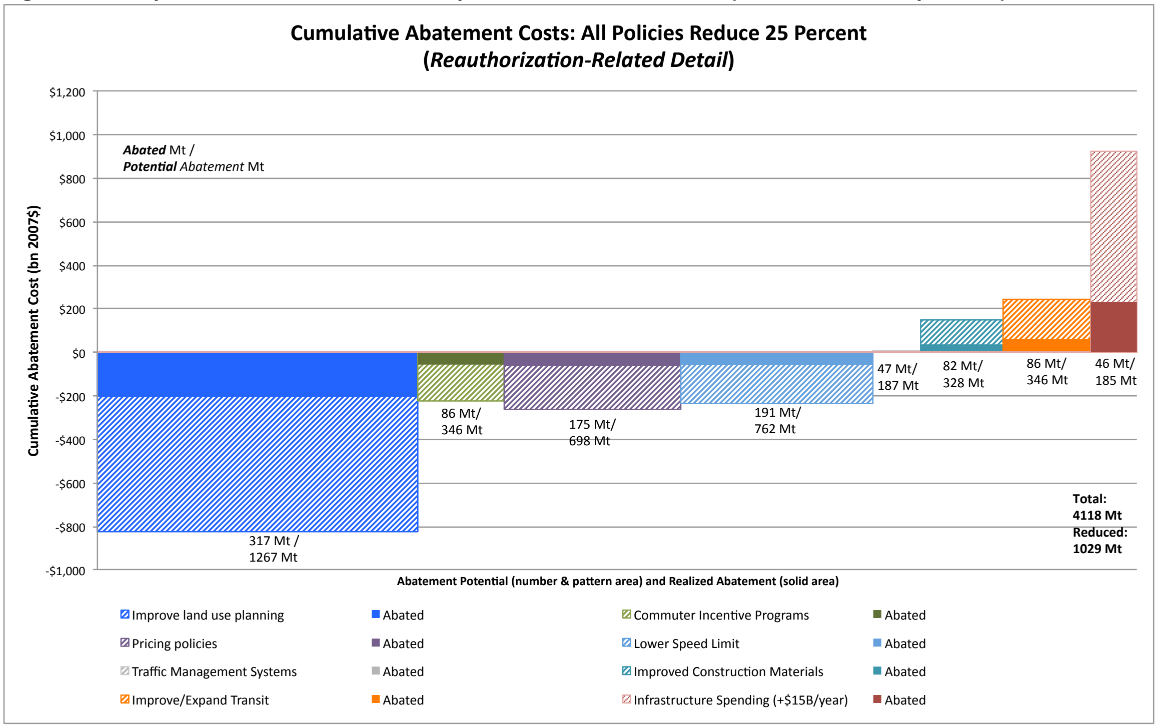
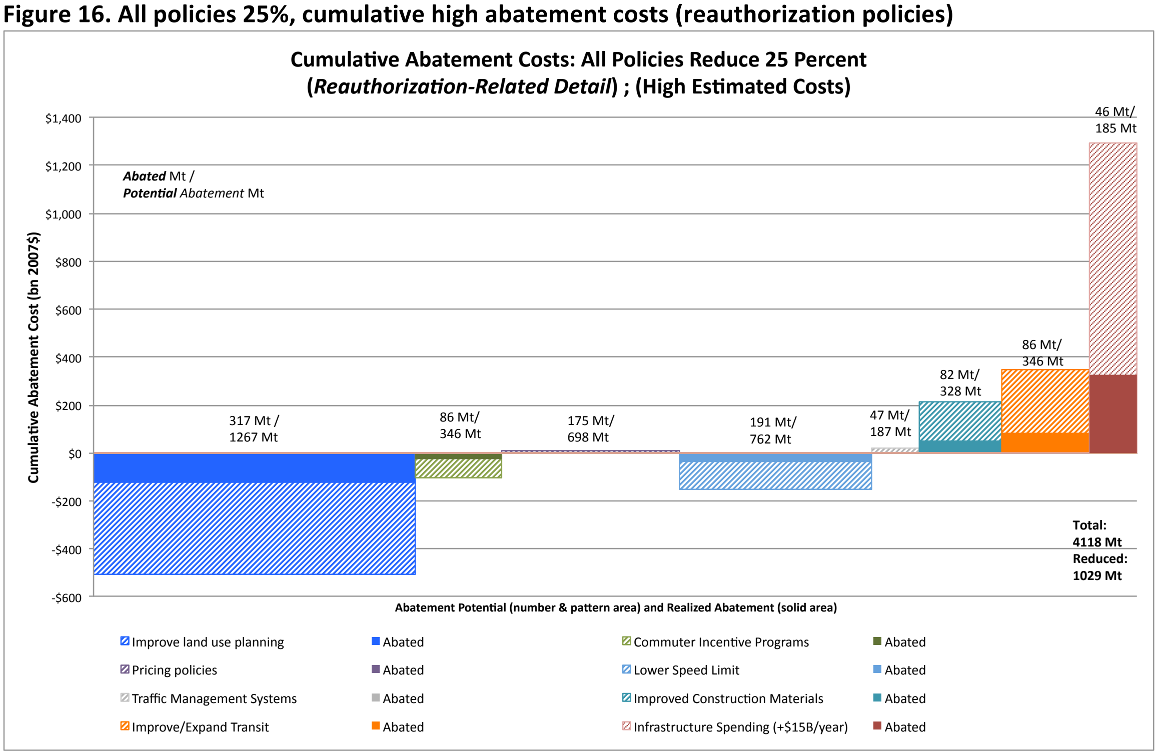


Figure 16. All policies 25%, cumulative high abatement costs (reauthorization policies)



CONCLUSION

Using results from a number of recent reports and academic papers, this paper shows that there is significant potential to reduce GHG emissions from the transportation sector. Policy makers seeking to use transportation policy to reduce GHG emissions have a number of potential tools, including some that could be considered as part of federal surface transportation reauthorization. Achieving maximum emissions reductions from the transportation sector would require also improving vehicle fuel efficiency and reducing the carbon content of transportation fuels. The framework presented in this paper for considering the emissions reduction potential and costs from transportation policies can be used to evaluate a wide range of policies.

Further work can inform effective policy development by focusing on four areas. First, as described in the policy brief, more accurate and refined cost data will dramatically improve estimates of the economic impacts from potential policies. Similarly, more exploration of cost-effective combinations of policies that distribute reductions across the three primary policy wedges should occur, so that total GHG effects or other policy drivers can be amplified while not over-burdening one segment of the transportation sector with reductions. All of these activities will require ongoing improvement of knowledge about the emissions and economic effects of potential policies, and improved modeling to explore how potential policies will translate into real-world outcomes across different regions and populations. Third, policy makers and stakeholders should attempt to identify policy tools that can quickly and cost-effectively achieve transportation sector GHG emissions reductions, so that the case can be made for implementing these policies in legislation under current development. Fourth, the linkages between climate outcomes and other policy drivers (e.g., economic development, household costs and equity, energy security) from transportation policy should be better understood so that strategic policy alliances can be built.

The most important challenge for reducing transportation emissions is the lack of agreement on goals and targets. Such agreement needs to be reached so that a framework for addressing goals through transportation policy can be developed. Unfortunately, reaching agreement on climate goals—or even reaching agreement that climate concerns need to be addressed—has so far proven impossible in the U.S. policy world. Opportunities to build broad consensus for other policy objectives associated with transportation do exist, although how closely those objectives align with climate interests should be considered. Stakeholders currently focused on reducing GHG emissions from transportation may achieve more immediate success by working with these other policy interests.

The task of reducing GHG emissions and energy consumption from the transportation sector is complex, and will require comprehensive short- and long-term solutions. This paper summarizes some of the best available information about GHG reductions possible through effective policy development, and explores the economic costs and benefits associated with those policies. But these advances highlight the need for ongoing work to improve the analytical potential surrounding GHG emissions and the transportation sector.

APPENDIX A: EMISSIONS REDUCTIONS, COSTS, AND ANALYSIS SOURCES

A number of recent reports were used to determine the potential range in absolute and percent reductions in GHG emissions used for this analysis. Primary sources include the following:

a) U.S. Department of Transportation. 2010. "Report to Congress: Transportation's Role in Reducing Greenhouse Gas Emissions." Washington, D.C.: U.S. Deparment of Transportation, June.
b) Greene, David, and S. Plotkin. 2011. "Reducing Greenhouse Gas Emissions from U.S. Transportation." Arlington, VA: Pew Center on Global Climate Change.
c) Cambridge Systematics. 2009. "Moving Cooler: An Analysis of Transportation Strategies for Reducing Greenhouse Gas Emissions." Washington, D.C.: Urban Land Institute.
d) Peterson, Thomas, J. Wennberg, et al. 2010. "Impacts of Comprehensive Climate and Energy Policy Options on the U.S. Economy." Johns Hopkins University and Center for Climate Strategies, July. http://www.climatestrategies.us/library/view/105.
e) U.S. Environmental Protection Agency. 2007. "A Wedge Analysis of the U.S. Transportation Sector." Washington, D.C.: U.S. Environmental Protection Agency.
f) Raborn, Craig. 2011. "Transportation and Climate Policy Summary: Greenhouse Gas Emissions Resulting from Different Infrastructure Spending Levels." Policy Brief NI PB 11-03. Durham, NC: Nicholas Institute for Environmental Policy Solutions, Duke University, June. http://nicholasinstitute.duke.edu/climate/policydesign/greenhouse-gas-emissions-resulting-from-infrastructure`spending-levels.
g) White, Peter, J. Golden, K. Biligiri, and K. Kaloush. 2010. "Modeling Climate Change Impacts of Pavement Production and Construction." *Resources, Conservation and Recycling* 54(10): 76–782.
h) Holland, Stephen, J. Hughes, and C. Knittel, "Greenhouse Gas Reductions under Low Carbon Fuel Standards?" *American Economic Journal: Economic Policy* 1, no. 1 (2009): 106–146.
i) Knittel, Christopher. 2009. "The Implied Cost of Carbon Dioxide under the Cash for Clunkers Program." National Bureau of Economic Research, August.
j) Chandra, Ambarish, S. Gulati, and M. Kandlikar. 2010. "Green Drivers or Free Riders? An Analysis of Tax Rebates for Hybrid Vehicles." *Journal of Environmental Economics and Management* 60(2): 78–93.
k) Lutsey, Nicholas. and D. Sperling. 2009. "Greenhouse Gas Mitigation Supply Curve for United States for Transport Versus Other Sectors." *Transportation Research Part D* 14: 222-229.

Notes and comments in Tables A-1 and A-2:
* Percentages reported in Greene and Plotkin (b) are adjusted to represent the potential reduction as a portion of total surface transportation emissions, rather than the portion of vehicle or fuel type. For example, according to AEO 2011, LDVs account for 68% of surface transportation emissions, so a 10% reduction for LDV emissions is approximately 6.8% of total surface transportation emissions.
[#] EPA "stabilization wedges" equal 5,000 Mt cumulative GHG emissions reductions by 2050; year-specific values presented here are estimated by author from a linear trend that achieves 5,000 Mt cumulative reductions.
** If combined with other policies, these values would exceed actual emissions. These values are reported here but adjusted downward for this paper in order to accommodate the combined effects of different policies.
^ This value does not include time-related savings, which are significant. Including time-related savings, the abatement effect is −$3,780/ton, a net benefit for consumers.
^^ Transit expansion reported in JHU/CCP (d) may not include implementation costs; previously reported similar values did not include these costs, but did include time-related costs.
*** Greene and Plotkin report estimates for 2035; those values are assigned to both 2030 and 2040.

Table A-1. GHG emissions reduction potentials and selected values (percentage from baseline)

***COMPARATIVE POLICY COMPONENTS** (source)*	2020	2030	2040	2050
Projected baseline emissions (Mt)	*1,712*	*1,689*	*1,671*	*1,653*
REDUCE TRAVEL DEMAND	**3.42**	**6.91**	**8.61**	**10.5**
Expected range	*(2.0-7.0)*	*(4.2-10.2)*	*(5.5-12.6)*	*(6.7-15.2)*
Travel demand "10 pct VMT reduction" (e[#])	*0.7*	*1.4*	*2.1*	*2.7*
Travel demand "15 pct VMT reduction" (e[#])	*1.0*	*2.0*	*3.0*	*3.9*
Infrastructure spending (+$15B/year)	**0.06**	**0.6**	**0.6**	**0.6**
Expected range	*(0.06-0.18)*	*(0.3-0.6)*	*(0.3-0.6)*	*(0.3-0.6)*
Highway bottleneck relief (a)	--	*0.06-0.4*	--	--
Bottleneck relief (c)	*0.18*	*0.18*	--	*-0.4*
Capacity expansion (c)	*0.12*	*0.12*	--	*-0.2*
Infrastructure spending (+$15B/year) (f)	*0.06*	*0.6*	--	--
Improve land use planning	**0.9**	**2.4**	**4.2**	**6.1**
Expected range	*(0.4-3.5)*	*(1.0-4.0)*	*(2.0-6.5)*	*(3.0-9.0)*
Land use (a)	--	*1.6-5.0*	--	*3.4-10.3*
Nonmotorized transportation (a)	--	*0.2-0.7*	--	--
Land use & infrastructure development (b)*	--	*1.0-2.0*	--	*3.0-5.0*
Combined land use (c)	*0.4*	*1.3*	--	*2.7*
Combined pedestrian policies (c)	*0.3*	*0.29*	--	*0.3*
Combined bicycle policies (c)	*0.06*	*0.12*	--	*0.12*
Smart growth/land use (d)	*4.2*	--	--	--
Pricing policies	**0.64**	**2.1**	**2.1**	**2.1**
Expected range	*(0.5-1.3)*	*(1.2-2.8)*	*(1.3-2.7)*	*(1.4-2.5)*
VMT fee (a)	--	*1.0-3.0*	--	--
Congestion pricing (a)	--	*1.1-2.6*	--	--
PAYD insurance (a)	--	*1.4-4.4*	--	--
Cordon pricing (c)	*0.06*	*1.2*	--	*0.18*
Congestion pricing (c)	*0.64*	*2.1*	--	*2.1*
Intercity tolls (c)	*0.12*	*0.12*	--	*0.12*
PAYD insurance (c)	*2.3*	*2.9*	--	*2.7*
VMT fee (c)	*1.5*	*1.4*	--	*1.3*
Improve/expand transit	**0.5**	**0.8**	**1.0**	**1.2**
Expected range	*(0.3-1.0)*	*(0.4-1.0)*	*(0.6-1.2)*	*(0.6-1.6)*
Transit expansion, promotion, service (a)	--	*0.4-1.1*	--	*0.5-1.9*
Transit frequency/LOS/extent (c)	*0.06*	*0.12*	--	*0.18*
Urban transit expansion (c)	*0.23*	*0.4*	--	*0.7*
Transit (d)	*1.6*	--	--	--
Lower speed limit	**1.2**	**2.0**	**2.1**	**2.3**
Expected range	*(0.8-2.3)*	*(1.6-2.5)*	*(1.8-3.2)*	*(2.0-4.0)*
Reduced speed limits (a)	--	*1.6-2.6*	--	--
Speed limit reductions (c)	*2.3*	*4.4*		*4.2*
Improved construction materials	**0.5**	**0.9**	**0.9**	**0.9**
Expected range	*(0.2-0.6)*	*(0.7-1.1)*	*(0.7-1.1)*	*(0.7-1.1)*
Construction materials (a)	--	*0.9-1.1*	--	--
Different road construction processes (g)	*0.5*	*0.7*	*0.9*	*1.1*
Traffic management systems	**0.18**	**0.24**	**0.6**	**1.0**
Expected range	*(0.1-0.25)*	*(0.24-1.5)*	*(0.6-1.6)*	*(0.8-1.6)*
Improved traffic flow (b)*	--	*1.0-2.0*	--	*1.0-2.0*
System operations [9 diff. Strategies] (c)	*0.0 – 0.26*	*0.5 - 5.0*		*0.3 - 1.6*
Commuter incentive programs	**0.9**	**0.83**	**0.8**	**0.8**
Expected range	*(0.5-0.9)*	*(0.5-1.0)*	*(0.6-1.1)*	*(0.7-1.3)*
Demand mgmt/commuter measures (a)	--	*0.4-0.8*	--	--
Ridesharing (b)*	--	*0.5-1.0*	--	*0.7-1.4*
Employer-Based Commute Strategies (c)	*0.9*	*0.83*		*0.79*
IMPROVE VEHICLE EFFICIENCY	**4.0**	**20.0**	**33.0**	**42.0**
Expected range	*(1.0-6.0)*	*(10.0-25.0)*	*(20.0-33.0)*	*(30.0-44.0)*
Fuel economy/emissions standards (b)*	--	*20.4-27.2*	*20.4-27.2*	*40.8-54.4*
Rail vehicle advanced technology (b)*	--	*0.5-0.6*	--	*0.9-1.2*
Vehicle purchase incentives (d)	*6.0*	--	--	--
Vehicle technologies (6 types) (e[#])	*0.5-2.3*	*0.9-4.6*	*1.4-6.7*	*1.8-8.7*
REDUCE FUEL CARBON CONTENT	**5.0**	**8.0**	**13.5**	**25.0**
Expected range	*(2.0-5.0)*	*(5.0-10.0)*	*(4.0-15.0)*	*(10.0-38.0)*
Low-carbon fuels (a)	--	*6.3-8.4*	--	*58.1-67.2*
Low-carbon fuel standard (b)*	--	*6.8-10.2*	*6.8-10.2*	*6.8-32.1*
Advanced biofuel (b)*	--	*2.3-3.5*	*2.3-3.5*	*3.5-8.6*
Renewable fuel standard (d)	*5.4*	--	--	--
Ethanol (60b gallons by 2050) (e[#])	*.01*	*2.2*	*3.2*	*4.2*

Table A-2. GHG emissions reduction potential and selected values (Mt)

***COMPARATIVE POLICY COMPONENTS** (source)*	2020	2030	2040	2050
Projected baseline emissions (Mt)	*1,712*	*1,689*	*1,671*	*1,653*
REDUCE TRAVEL DEMAND	**58.6**	**116.7**	**143.9**	**173.6**
Expected range	*(34.2-120.2)*	*(70.3-171.4)*	*(92.4-210.6)*	*(109.9-251.1)*
Travel demand "10 pct VMT reduction" (e$^{\#}$)	*12.0*	*23.6*	*35.1*	*44.6*
Travel demand "15 pct VMT reduction" (e$^{\#}$)	*17.0*	*33.8*	*50.1*	*64.5*
Infrastructure spending (+$15B/year)	**1.0**	**10.0**	**10.0**	**10.0**
Expected range	*(1.0-3.1)*	*(5.0-10.0)*	*(5.0-10.0)*	*(5.0-10.0)*
Highway bottleneck relief (a)	--	*1-6*	--	--
Bottleneck relief (c)	*3*	*3*	--	*-7*
Capacity expansion (c)	*2*	*2*	--	*-4*
Infrastructure spending (+$15B/year) (f)	*1.0*	*10.0*	--	--
Improve land use planning	**15.6**	**41.2**	**70.0**	**100.0**
Expected range	*(6.9-59.9)*	*(16.9-67.6)*	*(33.4-108.6)*	*(49.6-148.8))*
Land use (a)	--	*27-84*	--	*56-170*
Nonmotorized transportation (a)	--	*4-12*	--	--
Land use & infrastructure development (b)*	--	*16.9-33.8*	*16.7-33.4*	*49.6-82.7*
Combined land use (c)	*7*	*22*	--	*45*
Combined pedestrian policies (c)	*5*	*5*	--	*5*
Combined bicycle policies (c)	*1*	*2*	--	*2*
Smart growth/land use (d)	*71.04*	--	--	--
Pricing policies	**11.0**	**35.0**	**35.0**	**35.0**
Expected range	*(8.6-22.3)*	*(20.3-47.3)*	*(21.7-45.1)*	*(23.1-41.3)*
VMT fee (a)	--	*17-50*	--	--
Congestion pricing (a)	--	*19-43*	--	--
PAYD insurance (a)	--	*23-74*	--	--
Cordon pricing (c)	*1*	*2*	--	*3*
Congestion pricing (c)	*11*	*35*	--	*35*
Intercity tolls (c)	*2*	*2*	--	*2*
PAYD insurance (c)	*39*	*47*	--	*44*
VMT fee (c)	*25*	*24*	--	*22*
Improve/expand transit	**8.6**	**13.5**	**16.7**	**20.0**
Expected range	*(5.1-17.2)*	*(6.8-16.9)*	*(10.0-20.1)*	*(9.9-26.5)*
Transit expansion, promotion, service (a)	--	*6-18*	--	*9-32*
Transit frequency/LOS/extent (c)	*1*	*2*	--	*3*
Urban transit expansion (c)	*4*	*7*	--	*12*
Transit (d)	*27.05*	--	--	--
Lower speed limit	**20.5**	**33.0**	**35.5**	**38.0**
Expected range	*(13.7-39.4)*	*(27.0-42.2)*	*(30.1-53.5)*	*(33.1-66.1)*
Reduced speed limits (a)	--	*27-43*	--	--
Speed limit reductions (c)	*40*	*75*		*71*
Improved construction materials	**9.0**	**15.0**	**15.0**	**15.0**
Expected range	*(3.4-10.3)*	*(11.8-18.6)*	*(11.7-18.4)*	*(11.6-18.2)*
Construction materials (a)	--	*15-18*	--	--
Different road construction processes (g)	*8.6*	*11.9*	*15.0*	*18.2*
Traffic management systems	**3.0**	**4.8**	**9.9**	**16.5**
Expected range	*(1.7-4.3)*	*(4.1-25.3)*	*(10.0-26.7)*	*(13.2-26.5))*
Improved traffic flow (b)*	--	*16.9*	--	*16.5*
System operations [9 diff. Strategies] (c)	*0.5 - 4.5*	*0.5 - 5.0*		*5 - 27*
Commuter incentive programs	**15.0**	**14.2**	**13.5**	**13.5**
Expected range	*(8.6-15.4)*	*(8.5-16.9)*	*(10.0-18.4)*	*(11.6-21.5)*
Demand mgmt/commuter measures (a)	--	*6-14*	--	--
Ridesharing (b)*	--	*12-24*	--	*16-33*
Employer-based commute strategies (c)	*15*	*14*		*13*
IMPROVE VEHICLE EFFICIENCY	**68.5**	**337.8**	**551.4**	**694.3**
Expected range	*(17.1-102.7)*	*(16.9-422.3)*	*(334.2-551.4)*	*(495.9-727.3)*
Fuel economy/emissions standards (b)*	--	*345-459*	*341-455*	*674-899*
Rail vehicle advanced technology (b)*	--	*8.4-10.1*	--	*14.9-19.8*
Vehicle purchase incentives (d)	*103.07*	--	--	--
Vehicle technologies (6 types) (e$^{\#}$)	*8.6-39.4*	*15.2-77.7*	*23.4-112*	*29.8-144*
REDUCE FUEL CARBON CONTENT	**85.6**	**135.2**	**225.6**	**413.3**
Expected range	*(34.2-85.6)*	*(84.5-168.9)*	*(66.8-250.7)*	*(165.3-628.1)*
Low-carbon fuels (a)	--	*106-142*	--	*960-1110***
Low-carbon fuel standard (b)*	--	*115-172*	*114-170*	*112-531*
Advanced biofuel (b)*	--	*39-59*	*38-59*	*59-142*
Renewable fuel standard (d)	*92.34*	--	--	--
Ethanol (60b gallons by 2050) (e$^{\#}$)	*17*	*37*	*54*	*69*

Table A-3. Cumulative GHG emissions reduction potential (Mt) and abatement costs (reauthorization-related policies)

***COMPARATIVE POLICY COMPONENTS** (source)*	Cumulative (2012-2050) potential	**Abatement cost (expected)**	Abatement cost (high range)
Projected baseline emissions (Mt)	*67,706*	*$/t*	*$/t*
REDUCE TRAVEL DEMAND	**4,118**	**varies**	**varies**
Expected range		*(depends on mix)*	*(depends on mix)*
Travel demand "10 pct VMT reduction" (e[#])		--	--
Travel demand "15 pct VMT reduction" (e[#])		--	--
Infrastructure spending (+$15B/year)	**185**	**$5,000**	**$7,000**
Expected range			
Highway bottleneck relief (a)		--	--
Bottleneck relief (c)		*n/a*	*n/a*
Capacity expansion (c)		*n/a*	*n/a*
Infrastructure spending (+$15b/year) (f)		*$11,050^*	*$11,050^*
Improve land use planning	**1,267**	**-$650**	**-$400**
Expected range		*-$800 to -$1*	
Land use (a)		*-$700 to -$800*	*-$700 to -$800*
Nonmotorized transportation (a)		*-$390 to -$620*	*-$390 to -$620*
Land use & infrastructure development (b)*		--	--
Combined land use (c)		*-$750*	*-$750*
Combined pedestrian policies (c)		*-$690*	*-$690*
Combined bicycle policies (c)		*-$637*	*-$637*
Smart growth/land use (d)		*-$1.11*	*-$1.11*
Pricing policies	**698**	**-$375**	**$10**
Expected range		*-$930 to $60*	
VMT fee (a)		*-$370 to -$890*	*-$370 to -$890*
Congestion pricing (a)		*$60 to -$270*	*$60 to -$270*
PAYD insurance (a)		*-$870 to -$930*	*-$870 to -$930*
Cordon pricing (c)		*-$528*	*-$528*
Congestion pricing (c)		*-$373*	*-$373*
Intercity tolls (c)		*-$137*	*-$137*
PAYD insurance (c)		*-$901*	*-$901*
VMT fee (c)		*-$704*	*-$704*
Improve/expand transit	**346**	**$700**	**$1,000**
Expected range		*$17 to $4000*	
Transit expansion, promotion, service (a)		*$4000 to $300*	*$4000 to $300*
Transit frequency/LOS/extent (c)		*$46*	*$46*
Urban transit expansion (c)		*$784*	*$784*
Transit (d)		*$16.72^^*	*$16.72^^*
Lower speed limit	**762**	**-$310**	**-$200**
Expected range		*-$310 to -$322*	
Reduced speed limits (a)		*-$310*	*-$310*
Speed limit reductions (c)		*-$322*	*-$322*
Improved construction materials	**328**	**$450**	**$650**
Expected range		*$0 to $770*	
Construction materials (a)		*$0 to $770*	*$0 to $770*
Different road construction processes (g)		--	--
Traffic management systems	**186**	**$50**	**$120**
Expected range		*-$120 to $170*	
Improved traffic flow (b)*		--	--
System operations [9 diff. strategies] (c)		*$170 to -$120*	*$170 to -$120*
Commuter incentive programs	**346**	**-$650**	**-$300**
Expected range		*-$900 to -$615*	
Demand mgmt/commuter measures (a)		*-$900*	*-$900*
Ridesharing (b)*		--	--
Employer-based commute strategies (c)		*-$615*	*-$615*

Table A-4. Cumulative GHG emissions reduction potential (Mt) and abatement costs (vehicle efficiency and fuel intensity policies)

COMPARATIVE POLICY COMPONENTS (source)	Cumulative (2012-2050) potential	**Abatement cost (expected)**	Abatement cost (high range)
Projected baseline emissions (Mt)	*67,706*	*$/t*	*$/t*
IMPROVE VEHICLE EFFICIENCY	**13,361**	**-$200**	**$200**
Expected range		*-$200 to $365*	
Fuel economy/emissions standards (b)*		*~-$200*	*~-$200*
Rail vehicle advanced technology (b)*		--	--
Vehicle purchase incentives (d)		*-$66.37*	*-$66.37*
Vehicle technologies (6 types) (e#)		--	--
Cash-for-Clunkers program (i)		*$237 to $365*	*$237 to $365*
Hybrid vehicle tax credits (j)		*$195*	*$195*
REDUCE FUEL CARBON CONTENT	**6,694**	**$50**	**$350**
Expected range		*-$194 to $2,272*	
Low-carbon fuels (a)		*-$194 to $340*	*$340 to -$194*
Low-carbon fuel standard (b)*		*-$110 to $230*	*$230 to -$110*
Advanced biofuel (b)*		--	--
Renewable fuel standard (d)		*$57.14*	*$57.14*
Ethanol (60b gallons by 2050) (e#)		--	--
Low-carbon fuel standard (h)		*$307 to $2,272*	*$307 to $2,272*
Ethanol fuel substitution (k)		*-$21 to $94 ($31)*	*-$21 to $94 ($31)*
Biodiesel fuel substitution (k)		*-$26 to $128 ($51)*	*-$26 to $128 ($51)*

Table A-5. Summary expected and high abatement costs (and differentials)

TRANSPORTATION POLICY COMPONENTS	Abatement cost (expected cost)	Abatement cost (high estimate)	Difference (low minus high)
Projected baseline emissions (Mt)	*Dollar/ton*	*Dollar/ton*	*Dollar/ton*
Infrastructure spending (+$15b/year)	$5000	$7000	+$2000
Improve land use planning	-$650	-$400	+250
Pricing policies	-$375	$10	+$385
Improve/expand transit	$700	$1,000	+$300
Lower speed limit	-$310	-$200	+$110
Improved construction materials	$450	$650	+$200
Traffic management systems	$50	$120	+$70
Commuter incentive programs	-$650	-$300	+$350
COMBINED TRAVEL DEMAND POTENTIAL[20]	Varies	Varies	Varies
REDUCED VEHICLE ENERGY CONSUMPTION	-$200	$200	+$400
REDUCED FUEL ENERGY INTENSITY	$50	$350	+$300
TOTAL COMBINED REDUCTIONS (Mt)	Varies	Varies	Varies

[20] Potential combined reauthorization-related policies are 70% of the additive effects from these policies. This reduction factor is applied to approximate expected interactions of the different policies. More research on the interactions of policies to reduce transportation GHG emissions is needed to provide policy makers with the most effective understanding of expected effects from combined policies.

APPENDIX B: REAUTHORIZATION-RELATED POLICIES' GHG ABATEMENT COSTS

The following two figures show the expected per-ton and cumulative GHG abatement costs for policies discussed in this paper that are typically within the legislative policy scope of federal surface transportation reauthorization (higher estimated cost sets are shown in Appendix A, Tables A-3 to A-5).

Figure B-1. Expected abatement costs; reauthorization-related policies

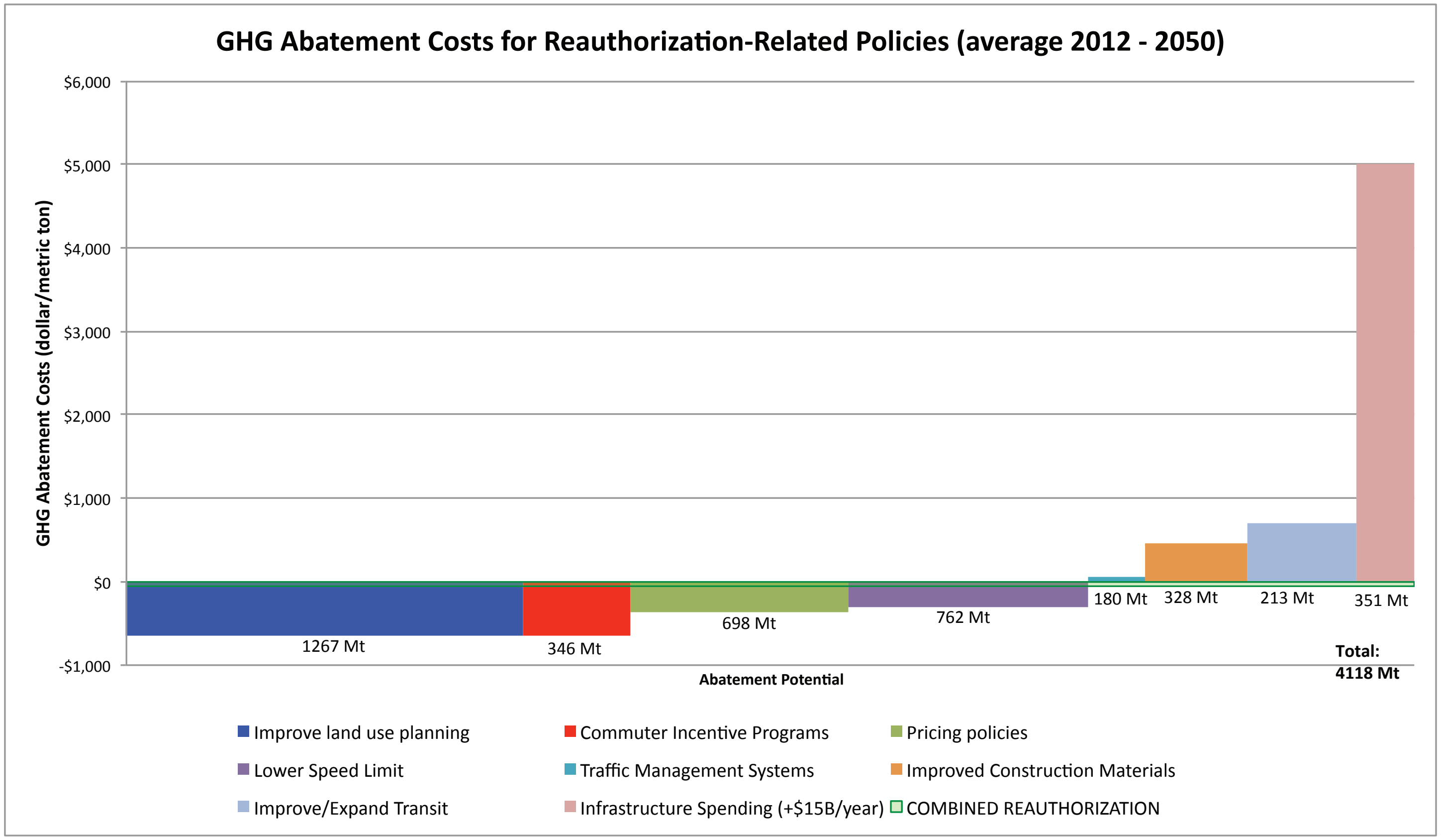


Figure B-2. Cumulative expected abatement costs; reauthorization-related policies