MINETA NATIONAL TRANSIT RESEARCH CONSORTIUM

Transportation Futures: Policy Scenarios for Achieving Greenhouse Gas Reduction Targets

MNTRC Report 12-11

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REPORT 12-11

TRANSPORTATION FUTURES: POLICY SCENARIOS FOR ACHIEVING GREENHOUSE GAS REDUCTION TARGETS

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16. Abstract

It is well established that GHG emissions must be reduced by 50% to 80% by 2050 in order to limit global temperature increase to 2°C. Achieving reductions of this magnitude in the transportation sector is a challenge and requires a multitude of policies and technology options. The research presented here analyzes three scenarios: changes in the perceived price of travel, land-use intensification, and increases in transit. Elasticity estimates are derived using an activity-based travel model for the state of California and broadly representative of the U.S. The VISION model is used to forecast changes in technology and fuel options that are currently forecast to occur in the U.S., providing a life cycle GHG forecast for the road transportation sector. Results suggest that aggressive policy action is needed, especially pricing policies, but also more on the technology side. Medium- and heavy-duty vehicles are in particular need of additional fuel or technology-based GHG reductions.

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EXECUTIVE SUMMARY

Many states have established targets to reduce greenhouse gas emissions by 50-80% by 2050. The federal government has also established a 2020 target of reducing carbon emissions by 17% (based on a 2005 base). These targets are based on limiting global temperature increases to 2°C. While much of the reduction in emissions will come from the electric utility sector, the transportation sector must also contribute significant reductions over this time frame.

The goal of this study was to examine various policy options that can achieve large-scale reductions by 2040, based on the current time frame of Annual Energy Outlook forecasts. Existing regulations on light-duty vehicle fuel economy and carbon emissions are leading to rapid decreases in emissions. New heavy-duty fuel economy standards will also soon take effect. These are supplemented by the renewable fuel standard. But these efforts are unlikely to be sufficient to meet what will be challenging reductions in greenhouse gas emissions in the next 30 years. This study examined the degree to which three key travel-demand policies—road pricing, directing new population growth to more compact areas, and increasing the level of transit service—could contribute to reductions within this time frame.

The VISION model was used to estimate current trends in greenhouse gas emissions. This model accounts for expected changes in population, technology, and fuel options based on existing regulations. The model was updated with the most recent carbon emission and fuel economy standards for light- and heavy-duty vehicles. It accounts for life cycle greenhouse gas emissions, mainly associated with upstream production of fuels.

To forecast the changes from the three policy scenarios, the California activity-based travel demand model was used. This is a statewide model that covers all the regions of California. From this model a variety of travel-demand elasticity estimates were derived for each policy option. These were then applied to forecasts of future vehicle miles of travel from the VISION model while also accounting for potential error bands inherent in the modeling process.

Results provide useful information for understanding the effectiveness of alternative policies and any additional regulatory policies that might be needed to close the gap. Of the three travel demand management policies analyzed, only the pricing policy comes close to achieving the 50% emission reduction target over the period from 2000 to 2040, and this assumes both a doubling of the price of driving and the highest range of elasticity estimates from the model. Transit and land-use policies provide only minor reductions in emissions. Overall, this analysis suggests that reductions of about 20% to 40%—in addition to those provided through demand management strategies—may be necessary to meet aggressive mitigation goals.

Medium- and heavy-duty vehicles, primarily freight traffic, achieve only small reductions in emissions even with the pricing scenarios. Freight emissions would not be affected by transit or land-use policies. This suggests that further technological improvements far beyond current regulations will be required to reduce emissions from these vehicles.

These results are not inconsistent with other “gap” analyses that have been conducted. Most studies conclude that both aggressive technology policies and reductions in travel demand are needed to achieve large reductions in transportation greenhouse gas emissions. This study reveals a potential gap, particularly in emissions from medium- and heavy-duty trucks, without further regulatory action. The need to increase the price of travel to reduce demand is also critical if the transportation sector is to contribute to global efforts to help stabilize temperatures at no more than a 2°C increase.

I. INTRODUCTION

In 2010, greenhouse gas (GHG) emissions in the United States total nearly 6.8 billion metric tonnes of CO_2 equivalents. Of this total, the transportation sector was responsible for more than 1.8 billion metric tonnes of emissions, or 27.1% of total GHG emissions. While the industrial sector emits a greater share than transportation of total GHGs (29.8%), the transportation sector is the single greatest contributor of CO_2 to the earth's atmosphere in the U.S. and accounts for about 31.1% of all CO_2 emissions (Davis, Diegel, and Boundy 2012). Within the transportation sector, on-road sources account for about 86% of all emissions, of which light-duty passenger vehicles account for about three-quarters (United States Environmental Protection Agency 2011). Climate change experts have urged that restricting the global mean temperature rise to 2°C relative is necessary to avoid heightened risk to human and natural systems. This would require reducing emissions by 50% to 85% by the year 2050, with peak levels no later than the middle of this decade (IPCC 2007). The objective of this research is to evaluate what mix of policies and technology options are needed from the road transportation sector to achieve aggressive reductions in life cycle GHG emissions.

GHG emissions from transportation are the result of the dynamic interactions between human behavior, vehicle technology, and fuel technology. The total level of GHG emissions from transportation in the U.S. depends on four factors: travel demand, modes of transport, fuel economy of vehicles, and the carbon intensity of fuels. The latter requires a full assessment of life cycle GHG emissions, as the process of producing fuels, especially biofuels, may be quite energy intensive and may also result in other GHG emissions (including release of carbon from soil, and emission of methane and nitrous oxide from agricultural production).

Federal and state authorities in the U.S. have limited direct influence on travel demand beyond levying taxes on transportation fuels; therefore, the national agenda for reducing GHG emissions from transportation falls into two general regulatory frameworks: corporate average fuel economy (CAFE) standards and GHG standards—jointly set by the National Highway Transportation Safety Administration (NHTSA) and the U.S. Environmental Protection Agency (EPA)—and Renewable Fuel Standards (RFS), which are set by the EPA and are intended to regulate the carbon intensity of the fuel supply. The 2007 Energy Independence and Security Act mandates the use of a variety of renewable fuels up to 2022. In addition to these regulations, various federal incentive programs have been established for both the supply and demand sides of the light-duty vehicle market. These incentives seek to ensure that the future composition of the light-duty vehicle fleet will include higher shares of more fuel-efficient vehicles.

While gains in vehicle efficiency are mandated by regulations, resulting reductions in per-mile GHG emissions will be offset by increased demand for vehicle travel. Recently there has been a reduction in VMT, both in total and per capita. However, while this may be influenced by a variety of factors, much of it is likely due to a weak economy, and growth is likely to resume as the economy grows (Millard-Ball and Schipper 2011; Taylor et al. 2013)

Current estimates of the total VMT for light-duty vehicles (LDV, cars and two-axle light trucks fewer than 10,000 pounds) for 2010 range from approximately 2.65 billion to 2.83 billion VMT per year (Davis, Diegel, and Boundy 2012; McCollum and Yang 2009, 5580-5596; Cambridge Systematics 2009). The Annual Energy Outlook (AEO) forecasts that between 2010 and 2035 VMT from LDVs will grow at an average rate of 1.2% annually (EIA 2013). The landmark Moving Cooler report forecast growth in VMT from LDVs at 1.4% annually from 2010 to 2050, and the authors used 1.0% and 1.6% growth rates to test the sensitivity of their projections to increased or decreased fuel costs (Cambridge Systematics 2009). Extrapolating from trends in the 2008 AEO, McCollum and Yang decomposed LDV VMT into a function of population and travel demand per capita for light-duty vehicles, with population growing a total of 69% between 1990 and 2050 and LDV VMT per capita growing by 71%, assuming vehicle load factors remain constant. The combined increases in population and transportation intensity approximate a 2.1% average annual growth rate over a 60-year period (McCollum and Yang 2009, 5580-5596). Although a variety of assumptions drive these forecasts, population growth alone will cause VMT to grow significantly between 2010 and 2050. Although it is uncertain whether VMT growth will follow historical trends, total VMT for LDVs could perhaps double, highlighting the need to aggressively pursue increases in fuel efficiency and decreases in the carbon intensity of fuels.

II. FEDERAL POLICY CONTEXT

CAFE STANDARDS

Corporate Average Fuel Economy (CAFE) standards were first enacted through the Energy Policy and Conservation Act of 1975. The CAFE program requires the NHTSA to set fleet-wide average efficiency requirements for automobile manufacturers. In August of 2012, the Obama administration unveiled aggressive new CAFE standards for passenger cars and light trucks to be deployed in two phases. Phase I covers automobiles produced in MY2017 through MY2021 and requires passenger cars and light trucks to achieve a combined average fuel economy of 40.3 to 41.0 miles per gallon (MPG), or an increase of about 38% over vehicles produced in MY2012. For the first time, NHTSA also issued "augural" standards, which are nonbinding standards extending beyond the agency's statutory authority to set regulations for a period of up to five model years. Phase II of the standards includes MY2022 – MY2025, and requires a combined average of 48.7 to 49.7 MPG for passenger cars and light trucks. (Davis, Diegel, and Boundy 2012; NHTSA 2012). These new standards are advertised as 54.4 MPG. This is equivalent to the CO_2 emissions regulations from the EPA, which require reducing the carbon intensity of cars and light trucks to 163 grams of CO_2 per mile by 2025. Some of the reductions in GHG emissions will come from non-fuel economy improvements such as reducing air-conditioning leakage.

CAFE standards influence LDV emissions in two primary ways. First, vehicle producers ramp up production of their most efficient vehicles to meet the sales-weighted average requirements, thus influencing the composition of the on-road fleet. As modeled by the National Energy Modeling System, the more stringent standards are likely to increase the sales of all vehicles utilizing battery technologies. Second, the standards increase the fuel economy of most vehicles, including those using conventional internal-combustion-engine (ICE) technology (EIA 2012). Prior to final rulemaking, NHTSA evaluated the impacts of the final and augural standards on consumers, energy independence, and the environment. The agency estimated the standards could save up to 4 billion barrels of oil and 1.8 billion metric tonnes of carbon emissions over the lifetimes of MY2025 vehicles. While consumers will pay more for more efficient vehicles, NHTSA estimates an increased average cost of up to $1,400 would be offset by savings on fuel within three years (NHTSA 2012).

In addition to more stringent standards for LDVs, in 2011 EPA and NHTSA finalized the first-ever fuel economy and GHG standards for medium- and heavy-duty vehicles (MDVs and HDVs). The standards vary by vehicle classes based on function and weight, and are expressed in grams of CO_2, or gallons of fuel perton-mile. The standards apply to combination tractor-trailers—typically, movers of freight goods—in a variety of cab configurations and roof heights. They are expected to achieve reductions in fuel consumption and emissions of 9% to 23%, compared with the 2010 baseline (United States Environmental Protection Agency, Office of Transportation and Air Quality 2011). Diesel and gasoline-powered heavy-duty pickup trucks and vans will also be required to achieve 15% reductions in fuel consumption and GHG emissions by MY2017. Vocational vehicles, which include delivery trucks, buses, and garbage trucks, will also be require to reduce fuel consumption and emissions by approximately 10% by MY2017. These standards are shown in Table 1.

Table 1. Fuel Economy and GHG Standards for Medium- and Heavy-Duty Trucks

		Emissions Standards, MY2017(g CO_2/ton-mile)			Fuel Consumption Standards, MY2017 (gal/1,000 ton-miles)		
		Low-Roof	Mid-Roof	High-Roof	Low-Roof	Mid-Roof	High-Roof
Combination Tractor-Trailers	Day Cab Class 7	104	115	120	10.2	11.3	11.8
	Day Cab Class 8	80	86	89	7.8	8.4	8.7
	Sleeper Cab Class 8	66	73	72	6.5	7.2	7.1

		Emissions Standards, MY2017 (g CO_2/ton-mile)	Fuel Consumption Standards, MY2017 (gal/1,000 ton-miles)
Vocational Vehicles	Light Heavy Class 2b - 5	373	36.7
	Medium Heavy Class 6 - 7	225	22.1
	Heavy Heavy Class 8	222	21.8

RENEWABLE FUEL STANDARDS

While CAFE standards have been proven to be an effective regulatory measure for increasing fuel economy and, thus, reducing per-mile GHG emissions, Congress has also recognized the need to reduce the carbon intensity of transportation fuels. The Renewable Fuel Standard (RFS)—a set of volumetric regulations mandating the production of lower-carbon fuels from renewable feedstocks—was established first by the Energy Policy act of 2005 and amended by the Energy Independence and Security of 2007 (EISA). Under the latest regulations, the EPA is required to set yearly standards for suppliers and refiners of transportation fuels. Standards govern the production volumes of cellulosic biofuels, biomass-based diesel, advanced biofuel, and renewable fuels to be used as transportation fuel or blended with gasoline or diesel fuels. Standards are measured in terms of actual volume, ethanol-equivalent volumes, and renewable fuels as a percentage of nonrenewable gasoline and diesel fuels sold on the market. Table 2 illustrates the 2012 RFS, including descriptions of regulated fuels and feedstocks. In addition to these yearly requirements, the EISA specifies that production shall rise to 36 billion gallons of renewables by 2022 (National Research Council 2011).

In order to track compliance, obligated parties must assign Renewable Identification Numbers (RINs) to each gallon or batch of renewable fuel. RINs track each unit of fuel from production through sale. This tracking system also facilitates a trading system: obligated companies who have not blended the mandated quantity of alternative fuels may purchase RINs from companies that have blended biofuels beyond the current mandate. Table 2 shows, through September 2012, with the exception of biodiesel, fuel suppliers in the United States are not on track to meet Renewable Volume Obligations (RVO). This is especially true for cellulosic biofuels. Only one batch of approximately 20 thousand gallons of cellulosic fuel was produced in April 2012. The only RFS fuel-type with significant production levels is the category of “Renewable Fuels,” mostly due to widespread blending of ethanol into gasoline. These shortfalls in production have made compliance with RFS extremely difficult, especially as far as cellulosic biofuels are concerned, and the EPA is required to lower the standard for cellulosic biofuels when projected volume is less than the mandated volume (Bracmort 2010). In December of 2012, in deciding a claim brought

by the American Petroleum Institute, the District of Columbia Circuit Court vacated the EPA's 2012 standard for cellulosic biofuels. The outcome of this case may lead to changes in the agency's method for setting yearly standards (American Petroleum Institute, Inc. v. Environmental Protection Agency [2013] No. 12-1139 U.S.C.A.-D.C.).

Table 2. Renewable Fuel Standards for 2012

Fuel	Description	Actual Volume (Gal)	Ethanol Equivalent Volume (Gal)	Percentage Standard
Cellulosic biofuel	Fuel derived from cellulose, hemicellulose, or lignin. Emissions at least 60% less than baseline.	8.65 Million	10.45 million	0.006%
Biomass-based diesel	Either biodiesel derived from animal or vegetable fats or non-ester renewable diesel derived from biomass, and which is not co-processed with petroleum. Emissions at least 50% less than baseline.	1.0 Billion	1.5 Billion	0.91%
Advanced biofuel	Renewable fuel, other than corn ethanol. Emissions at least 50% less than baseline.	2.0 Billion	2.0 Billion	1.21%
Renewable fuel	Any fuel, including ethanol, that is produced from renewable biomass. Emissions at least 20% below baseline.	15.2 Billion	15.2 Billion	9.23%

Notes: Baseline emissions are from either gasoline or diesel fuel, whichever the renewable is designed to replace. "Ethanol Equivalent Volume" is the volume of ethanol fuel with the same amount of energy as the actual volume of a particular fuel. "Percentage Standards" are the ratio of renewable fuel volumes to non-renewable gasoline and diesel fuel volumes.

Source: EPA, December 2011. 75 FR 14863, Mar. 26, 2010.

Forecasts from the 2013 AEO early release indicate that the growth rate in consumption of renewable energy will be greater than that for fossil fuels, across all sectors. However, this is mostly due to increased solar electricity production and not liquid fuels used for transportation. The projection for biomass-based liquid fuels in 2035 was adjusted downward 24% (from 5.4 to 4.1 quadrillion btu) from projections made in the previous report (EIA 2013; Energy Information Administration 2012).

Table 3. Renewable Fuel Production, Jan. – Sep. 2012

Fuel	Production Through September 2012 (Gallons)	Ratio of Production to RVO
Cellulosic biofuel	20,069	0.002
Biomass-based diesel	897,445,920	0.897
Advanced biofuel	316,102,248	0.158
Renewable fuel	9,837,836,787	0.647

Because of the lack of success with volumetric regulations, some researchers and environmental organizations propose supplementing federal requirements with low-carbon fuel standards (LCFS), which operate in a similar way to a cap-and-trade system. An LCFS program would specify carbon-intensity performance targets for fuel producers and establish a credit trading system (Yeh et al. 2012b). As of 2012, only California's Air Resources Board (CARB) has officially adopted an LCFS; Oregon, Washington, and

eleven member-states of the Northeast States for Coordinated Air Use Management are currently developing or considering LCFS regulations (Center for Climate and Energy Solutions). Advocates of the LCFS point to the potential for lost investment due to regulators "picking winners" incorrectly. They believe that, given performance standards, producers will be able to effectively reduce the carbon intensity of their total fuel output, achieving an additional net 3.4% in emissions reductions, compared with RFS alone after accounting for rebound effects and land-use changes (Yeh et al. 2012a).

OTHER FEDERAL POLICIES

In addition to CAFE standards and RFS requirements, the Federal government has several policies that seek to reduce the GHG impacts from the LDV sector. The Alternative Motor Fuels Act of 1988 and Clean Air Act Amendments of 1990 encouraged the production of alternative-fuel vehicles and ultimately established the Department of Energy's Clean Cities Program, which establishes partnerships and supports local government actions to reduce transportation-related air pollutant and GHG emissions (United States Department of Energy 2012). Recently, consumers and manufacturers of alternative fuel vehicles and infrastructure have been able to take advantage of incentive programs, such as the Advanced Energy Manufacturing Tax Credit and Alternative Fuel Infrastructure Tax Credit. These programs provide for tax credits equal to 30% of the cost of establishing facilities to develop clean energy vehicles or the costs incurred by consumers who install alternative fueling equipment at their home or business. The Innovation Technology Loan Guarantee Program provides subsidized loans to promote technologies to reduce or capture air pollutants including GHGs (CBO 2012).

The American Recovery and Reinvestment Act (ARRA) also created new federal income tax credits for consumers who purchase electric vehicles. Credits range from $2,500 for vehicles with batteries rated at 4 kWh, up to a maximum of $7,500 for vehicles with batteries rated 16 kWh or greater. Although credits apply only to the first 200,000 electric vehicles sold by each manufacturer, the Congressional Budget Office estimated that a total of only 40,000 electric vehicles have been sold in the United States as of late 2012, with three models (the Chevrolet Volt, Toyota Prius Plug-in Hybrid, and Nissan Leaf) accounting for nearly all sales. This number may have increased substantially in 2013: by one estimate, 78,000 new plug-in hybrid and battery electric vehicles (including those with an gasoline-extended range) have been purchased in the first three-quarters of 2013 (Electric Drive Transportation Association 2013). Eligible consumers may deduct tax credits from the amount of federal income tax they owe but do not receive a refund for credits exceeding their total tax liability. In addition to consumer tax credits, ARRA also provided a number of subsidies, totaling $7.5 billion, which will influence the supply and cost of electric vehicles. The Electric Drive Battery and Component Initiative provides $2 billion in funding for the grants administered by the Department of Energy (DOE) to encourage the production of batteries and other components of electric vehicles. The DOE estimates this funding will result in a total battery production capacity of about 500,000 units by 2015. The Advanced Technology Vehicles Manufacturing Program provides up to $25 billion in direct loans to manufacturers of vehicles and components to promote the production of high-efficiency automobiles. Finally, the Transportation Electrification Initiative provides $400 million in grants to accelerate the introduction of EVs into the marketplace (CBO 2012).

III. PRIOR POLICY ANALYSIS

A small but growing portion of the literature on the GHG impacts of the transportation sector has shifted from modeling expected reductions from particular strategies to comparing policy scenarios in which a variety of policies result in reduced future emissions compared to baseline projections. These "gap-analysis" studies focus on helping policy-makers understand the likely quantity of emissions that will result, given existing policies and trends. From this, one can determine whether additional measures are needed to meet reduction targets. It is thus assumed that each policy under consideration is more or less effective in altering one of the key transportation inputs, such as travel activity or fuel economy, and this provides an understanding of how each policy contributes to reaching the reduction target.

Reduction goals vary from study to study but are usually set to be commensurate with existing or considered policies. One possible set of benchmarks is the mandated reductions that would have been required across all sectors by the cap-and-trade provisions of the American Clean Energy and Security Act of 2009—commonly known as the Waxman-Markey bill—which passed in the House of Representatives but failed to advance in the Senate. The bill required reductions from 2005 emissions levels of 17% by 2020, 42% by 2030, and 83% by 2050 (Waxman 2009). In addition to varying in benchmarks, studies also examine the a variety of behavioral, technological and planning strategies. These frequently include policies that influence VMT growth, smart growth policies, policies to advance the development and supply of less carbon-intensive fuels, policies that influence the on-road fuel economy of the vehicle fleet, and local, regional and economy-wide pricing measures.

One limitation of studies that focus solely on the transportation sector is that economy-wide GHG reduction goals may not distribute the burden of reduction equally among sectors due to the varying marginal cost for abatement. For instance, in an economy-wide study to which six modeling teams contributed scenarios for an 80% reduction in emissions by 2050, reductions from the transportation sector were much smaller than reductions from the electricity sector in scenarios from all teams (Fawcett et al. 2009). Achieving deep reductions in the transportation sector may be more costly and difficult than achieving deep reductions in other economic sectors. It may not be appropriate to assume that abatement burdens should be distributed proportionally among sectors.

Among the first comprehensive review of strategies to achieve significant reductions in the GHG impact of transportation was the landmark Moving Cooler report, prepared by Cambridge Systematics. Various bundles of strategies were evaluated with respect to their potential to reduce GHG emissions, the cost of implementation, changes in the cost of vehicles, and possible concerns of inequitable distribution of burdens and benefits. Moving Cooler evaluated combinations of nearly 50 separate strategies that fell into nine major categories (Cambridge Systematics 2009), as outlined in Table 4.

Table 4. Moving Cooler Strategies

Strategy	GHG Reduction Mechanism
Pricing and taxes	Raising cost of using transportation system results in reduced demand for transportation
Land use & smart growth	More efficient land-use patterns result in fewer, shorter automotive trips
Public transportation improvements	Subsidies, increased service, and new infrastructure result in mode shift to transit
Ridesharing, carsharing, and other commuting strategies	Expanded service options and provide incentives to shift single-occupant trips to multiple occupants, reducing the number of trips and VMT
Regulatory strategies	Regulations that moderate vehicle travel to reduce total VMT, or speed reductions resulting in higher operating fuel efficiency
Operational and ITS strategies	Strategies that encourage more fuel-efficient driving or make better use of existing capacity, resulting in less fuel consumption for existing trips
Capacity expansion & bottleneck relief	Strategies that reduce congestion, resulting in more efficient fuel consumption for existing trips
Multimodal freight strategies	Improvements that increase the efficiency of freight transportation of all modes

To test the sensitivity of various policy bundles, several Moving Cooler baselines were developed using projections of GHG emissions through the year 2050 based on rates of vehicle and fuel technology improvement. The official study baseline was designed to be consistent with the DOE AEO, with reductions to be measured against 2005 levels. Four other baselines were developed for sensitivity testing, including scenarios with then-proposed 35.5-MPG CAFE standards and varying projections for fuel prices, VMT, and the rate of technology advancement. For the year 2050, the baseline with the then-existing fuel-economy improvements fell short of even the 17% reduction from 2005 levels that would have been required by 2020 under the Waxman-Markey bill. Without economy-wide pricing measures, such as a carbon or VMT tax, the report's authors found that reductions of 4% to 18% from the baseline were possible with "aggressive" deployment of strategies, including local and regional pricing, smart growth, encouraging eco-driving, and other measures; a 28% reduction from the baseline was attainable using the same strategies under conditions of "maximum" deployment. The report also concluded that including economy-wide pricing measures, such as a carbon tax, would lead to much greater reductions in emissions: a bundle that included a fee equivalent to a $2.40-per-gallon fuel tax in 2015, increasing to $5.00 per gallon in 2050, was found to result in an additional 28% reduction in GHG emissions.

One recent study developed scenarios for the LDV sector that decompose emissions reductions into those resulting from lower VMT, fuel-efficiency improvements, and lower fuel carbon intensity (Melaina and Webster 2011, 3865-3871). In these scenarios, large improvements in LDV fuel economy (of up to 65 to 110 miles per gallon of gasoline-equivalent fuel) provide the bulk of the reduction. VMT is also reduced from 9% to 21% and fuel carbon intensity by 65% to 77%. The authors compare scenarios with greater contributions from VMT and contributions from lower-carbon fuels. The authors also highlight that although passenger vehicles are the largest source of transportation emissions, vehicle design limits in other transportation sectors will likely lead to preferential consumption of available biofuels.

Two detailed scenario analysis studies were conducted that examined policy options for achieving deep emissions reductions in the transportation sector, both in California and nationally. (McCollum and Yang 2009, 5580-5596; Yang et al. 2009, 147-156). The benchmarks for reductions used in these studies stem from Executive Order S-3-05, which called for reductions of 80% from 1990 levels by 2050, a rate that California's Environmental Protection Agency advised was necessary to avoid catastrophic climate change. Strategies to meet this goal in the entire transportation sector were considered and evaluated using a model that identifies CO_2 emissions as a function of four drivers: population, travel demand, vehicle fuel consumption and fuel carbon intensity.

For the California-only study the reference scenario is constructed such that, relative to 1990, the population doubles, transportation demand increases by 21% and energy intensity is improved by 35% across all transportation subsectors, yielding a 61% increase in emissions between 1990 and 2050. A series of scenarios was developed that examined the effects of moderate and high-efficiency gains; aggressive deployment of hydrogen technologies (60% of on-road fleet in 2050 and 58% of all VMT); advances in low-carbon electrification, allowing electric vehicles to provide 77% of all on-road VMT; a biofuel-intensive scenario in which low-carbon biofuels provide 15% to 20% of liquid fuel supply but 59% of VMT; and 25% to 50% reductions in demand for passenger travel through smart growth and transit investments. The authors concluded that none of these individual strategies, even under optimistic assumptions about their potential, could meet the 80% reduction goal (Yang et al. 2009, 147-156).

Three combination scenarios that can meet the reduction goal are described. The first scenario is predicated upon a high dependence on biofuels across all subsectors (83% of fuel) plus high penetration of PHEV vehicles in the light-duty market. The second successful scenario combines aggressive turnover of the on-road fleet to BEV, PHEV, and FCVs, with a significant level of biofuel consumption (32%). Finally, an "actor-based" scenario describes achieving an 80% reduction through reduced travel activity; increased vehicle occupancy factors; limited uses of hydrogen and electricity in non-LDV subsectors; and high gasoline prices that that encourage consumers to purchase smaller and more efficient vehicles, such as PHEVs, yielding a 76% reduction in transportation energy intensity, or the equivalent of an LDV fleet-wide average of 125 MPG. The authors conclude that it is highly unlikely that reduction goals can be met by addressing the GHG impacts of LDVs alone, and that existing targets can be met only through sustained policy frameworks that include behavioral change measures (Yang et al. 2009, 147-156).

Comparable results were obtained in the national-level study (McCollum and Yang 2009, 5580-5596). A biofuel-intensive scenario was able to reduce emissions 50% from 1990 levels by 2050 by lowering the carbon intensity of fuels by 47%, assuming a 100% substitution rate for conventional petroleum in the LDV sector and a 20% substitution in the HDV sector. This scenario also assumes slower VMT growth than the reference scenario. The electrification scenario for a 50% reduction in GHG emissions simulates a sector-wide reduction in carbon intensity of 41% through widespread electric vehicle penetration. The scenario assumptions are that 30% and 5% of LDV miles and HDV miles, respectively, and 100% of rail miles, are traveled using electric drive propulsion; VMT growth is slowed; a small amount of hydrogen is used in marine travel; and the aviation sector consumes

biofuels roughly corresponding to the RFS requirements (21 billion gge). The authors also effectively achieved an 80% reduction relative to 1990 emissions levels by combining aspects of these two scenarios. In this “80in50” scenario, LDVs (the most flexible in terms of fuel technology) are nearly entirely electrified or hybridized with biofuel, diverting large amounts of biofuels to the aviation, marine, and commercial freight sectors. Although each of these scenarios assumes major technological breakthroughs, smart growth, mode shift and pricing policies leading to reductions in VMT also provide significant reductions of 810 million metric tonnes of CO_2e.

Similar conclusions have been reached by researchers from the energy companies themselves (National Petroleum Council 2012; Skippon et al. 2012, 1405-1423). In 2010, Secretary of Energy Steven Chu requested the National Petroleum Council provide an analysis of conditions under which the United States could achieve a 50% reduction in GHG emissions (relative to 2005) by the year 2050. Emissions in the light-duty sector would have to decrease from the 2005 level of about 1500 million metric tonnes to 750 million metric tonnes or fewer, and the medium- and heavy-duty sector would need to decrease from the approximately 500 million metric tonnes in 2005 to 250 million metric tonnes or fewer. In both sectors, growth in travel demand alone could increase light-duty emissions to between 2400 and 2700 million metric tonnes and heavy-duty emissions to between 900 and 1000 million metric tonnes. GHG emissions levels of between 700 and 1000 million metric tonnes could be achieved if all technologies examined were commercialized. However, only a very small percentage of scenarios (3%) were able to achieve the 50% reduction goal through a combination of increased improvements in fuel economy, low-end growth in VMT, availability of significant levels of economically viable cellulosic biofuels, and significant shares of hydrogen fuel cell vehicles. For heavy-duty vehicles, GHG emission levels could be reduced to between 350 and 500 million metric tonnes. Scenarios that met the 50% reduction goal of 250 million metric tonnes could not be identified; however, significant reductions were possible by assuming a doubling in the fuel economy of the heaviest vehicles (classes 7 and 8), reducing the growth in VMT, availability of significant levels of biofuels for vehicle classes 3 through 6, and aggressive penetration of natural gas platform vehicles (NPC 2012).

Similarly, a study conducted by technology researchers at Shell found that even aggressive deployment assumptions combining all feasible technologies (improvements in ICE, low-carbon electrification, fuel cell vehicles for freight, and advanced biofuels) would reduce cumulative emissions from road transportation by only 34.1% from the baseline of 92.2 giga-tonnes for the 50 year period 2000-2050, far less than required to meet the proposed budget for the U.S. of 19 to 45 giga-tonnes[1] (Skippon et al. 2012, 1405-1423). The only scenarios below the high-end of that budget included the most aggressive behavior-changing and pricing measures from Moving Cooler. Of the five scenarios analyzed that reached 50% or fewer annual emissions in 2050 (relative to 2000), four included at least some mode shifting or travel demand management strategies.

In addition to national and state-level studies, at least one study has examined scenarios for reducing GHG emissions at the local and regional level (Brisson, Sall, and Ang-Olson 2012, 89-97). In 2008, San Francisco Ordinance 81-01 established a policy goal of reducing GHG emissions by 80% below 1990 levels by the year 2050. As part of the effort to quantify

the potential strategies for reaching this goal in the transportation sector, the San Francisco County Transportation Authority (SFCTA) examined the potential to meet an interim target of an approximately 50% reduction from 1990 levels by 2035. SFCTA used output from the regional travel demand model supplemented with sketch modeling, based on evidence from the empirical literature, to examine two major scenarios comprised of nine separate strategies. The study's "local bundle" includes transit network improvements (including bus rapid transit and a new heavy-rail line); improvements to the bicycle network (simulating an expansion of 4% to 10% mode-share increase); transportation demand programs for new residential buildings, employers, and schools; personalized travel marketing and outreach; a simulated $3 cordon charge for entrance to and exit from the downtown area; and a low-effort policy for increasing electric vehicle charging infrastructure, which results in a 9% penetration rate in 2035. The "regional bundle" includes the strategies from the local bundle, but adds two additional strategies: region-wide pricing measures that would double the per-mile cost of driving (to $0.48) and greater electric vehicle market penetration through increased efforts to deploy charging infrastructure and government incentives, estimated to result in penetration rates of 16% and 25%, respectively. Overall, the local bundle was expected to result in daily emissions reductions of 30% to 40% from the baseline, leaving a gap of approximately 1,100 to 1,300 mt per day. The regional bundle was expected to reduce vehicle trips by an additional 10%—for a total daily reduction of 65% to 85%—leaving a gap of between 300 and 700 metric tons per day.

These prior analyses differ somewhat in methodology, geographic scope, GHG targets, and the particular policy strategies and bundles examined, and the allocation of alternative fuels across subsectors. However, all reached the conclusion that to achieve deep reductions in GHG emissions by 2050, it will be necessary to curb growth in absolute VMT through policies that encourage fewer, shorter trips and shifting some trips to less-carbon-intensive modes than personal vehicles. This remains true even under scenarios that assume very aggressive technological changes to both vehicles and fuel sources. Our results support these conclusions. The major contribution of the current study is to apply the results from an activity-based model to updated estimates from the of VISION model, which is based on standard national forecasts of travel demand and vehicle fleets. VISION also provides a life cycle GHG estimate. In addition, customization of the VISION model described below provides the ability to analyze changes in VMT for medium- and heavy-duty vehicles.

IV. METHODS

The basic approach used here is based on the results of an activity-based model developed for the entire state of California. Three policy scenarios, as well as their combinations, were evaluated using this model. These include a pricing policy, a land-use policy and an increase in transit system service frequency. The modeling provides VMT elasticity estimates for policies that increase the cost of driving, variations in regional density, and the frequency of transit service, which can then can then be applied to national forecasts of VMT growth. See Appendix A for documentation of the modeling. These forecasts are based on Argonne National Laboratory's (ANL) VISION model, which is used for the development of AEO forecasts (Argonne National Laboratory). VISION also allows estimation of life cycle GHG emissions based on the VMT forecast. Because this analysis focuses exclusively on the transportation sector, it is important to analyze life cycle (well-to-wheel) emissions; it is important to include upstream emissions associated with fuel production, especially for biofuels. A brief overview of the activity-based model and details of how the VISION model was used to generate a variety of policy scenarios to examine any gap in achieving GHG reductions in the land-transportation sector (excluding rail) are provided.

SCENARIO DEVELOPMENT AND MODELING

The activity-based travel demand model for California (the CSTDM) was used to derive demand elasticities for various policies. The CSTDM is a statewide model featuring eight regions with distinct patterns of travel and development, shown in Figure 1. Two key assumptions about the generalizability of the modeling results are made for the purposes of this study. The first is that modeled reductions in travel demand in the scenarios can be extended from the 2035 planning horizon used in CSTDM to the 2040 horizon of the AEO embodied in VISION. Second, it is assumed that relationships between policies and travel demand in California are generalizable to the United States as a whole. While using a statewide model to represent the nation is not ideal, no model exists for detailed travel demand forecasting at the national level. In addition, California is a large state whose population is spread throughout a diversity of development patterns and regional forms—including dense urban cores, postwar suburbs, fast-growing sprawl, and rural areas—which are not unrepresentative of the range of settlement patterns in the United States. Furthermore, the elasticities generated from the model are similar to many other elasticities reported in the literature (Rodier 2009, 1-12).

Figure 1. California Regions in CSTDM

Three demand-management policy scenarios were analyzed. The first scenario involves intensifying land use by moving regional job and population growth closer to transit-oriented cores. This is represented in the model as an increase in weighted regional density, calculated as the sum of population and employment density in each travel analysis zone (TAZ) in each region, weighted by its share of total regional population and employment. Regional density does not change in this scenario relative to the baseline, but the number of people and jobs at higher local densities within the region increases, effectively increasing proximity to transit. The second scenario is improved transit service, represented in the model by increasing revenue miles of service for all modes of transit. The third scenario is a pricing policy, a VMT tax that increases the perceived marginal cost of driving. The original cost in the CSTDM is $0.14 per mile, a common figure in behavioral travel models; this is increased by 50% and 100% in the analysis. While this does not represent the average cost of driving which includes vehicle ownership costs, it is a reasonable representation of the marginal cost of driving associated with fuel costs and how people perceive those costs.

These scenarios were simulated individually and in combination with the others using the CSTDM, estimating arc elasticities with respect to VMT for three vehicle types, as shown in Table 5. As expected, the elasticities for transit improvement are zero for the truck categories, and those for pricing are very small, as increased costs to transport goods will be passed through to consumers. Medium-duty trucks, however, are quite responsive to the land-use scenario. This is likely because this vehicle category is comprised of smaller trucks used for intracity deliveries. As more firms agglomerate near regional cores, deliveries between them may require significantly shorter distances.

Table 5. VMT Elasticities for Policy Scenarios

	Arc Elasticity (With Respect to VMT)		
Scenario	**Cars and Light Trucks**	**Medium-Duty Trucks**	**Heavy-Duty Trucks**
Land Use (weighted population and employment density)	-0.31	-0.46	-0.01
Transit (revenue miles of service)	-0.02	0.00	0.00
Pricing (dollars per mile)	-0.30	-0.03	-0.05

DESCRIPTION OF THE VISION MODEL

VISION is a spreadsheet model developed by ANL for the U.S. Department of Energy (DOE) for the purpose of estimating energy use and carbon emissions from the year 2000 to the year 2100 from cars, light trucks (LTs) and heavy-duty vehicles (HDVs) operating on a variety of fuel-technology platforms. The model is built on two separate Microsoft Excel workbooks. The first workbook contains the "Base Case," which is used as a reference for comparing any modeled scenarios based on altering parameters in the second workbook. VISION is updated yearly with assumptions generally derived and extended from the AEO. The latest version available as of this writing is VISION 2012, based on the 2012 AEO, which features projections out to 2035. Fuel life cycle emissions factors embedded in the model are derived from ANL's GREET model (Singh, Vyas, and Steiner 2004; Ward 2008).

The model utilizes vehicle survival, sales, and usage characteristics to project future vehicle fleet composition, fuel consumption, and life cycle emissions based on several parameters that can be modified by the user. The LDV fleet in VISION is composed of twelve vehicle technologies:

- Conventional internal combustion engine (ICE)
- Electric vehicles (EVs)
- Flex-fuel vehicles capable of operating on 85% ethanol blends
- Compressed natural gas
- Spark-ignition hybrid electric vehicles (HEVs) operating on gasoline
- Spark-ignition HEVs operating on either E85 or hydrogen fuel
- Diesel HEVs
- Short-range plug-in hybrid electric Vehicles (PHEVs) with a default all-electric range of 10 miles
- Longer-range PHEVs with a default all-electric range of 40 miles
- Diesel PHEVs
- Fuel Cell Vehicles (FCVs)

The HDV fleet is composed of two vehicle classes. Class 3-6 trucks can operate on gasoline, diesel, diesel HEV, and natural gas platforms. Class 7-8 vehicles are divided into single-unit and combination trucks and can operate on conventional diesel, diesel HEV, and natural gas platforms.

Users can alter the following parameters for the last year in each decade (years ending in 0) up to 2100:

- Vehicle miles of travel (VMT)
- Market penetration and fuel economy ratio (compared with baseline ICE fuel economy) for new cars and LTs, by vehicle platform
- LT share of total LDV market
- Fuel prices and pathways (including diesel blends and ethanol and hydrogen feedstocks)
- HDV fuel economy, market share, and alternative fuel usage
- LDV cost

VISION includes multiple methods for modifying VMT forecasts. Method one is an exponential growth function. The number of years to zero growth is set to 200 by default but may be modified by the user. This method also allows the user to incorporate an elasticity for VMT with respect to the cost of driving (-0.1 by default). Using method two, VMT can be calculated using year-over-year growth factors by entering the desired VMT ratio for each year to the previous year. Method three is a hybrid: VMT grows according to the exponential function until a specified year, after which growth factors are used. The final method for VMT calculation is to instruct VISION to utilize annual VMT per vehicle estimates based on extended AEO projections for energy use, vehicle stock, and fuel economy, consistent with the default growth factors.

New vehicle sales are matched to AEO estimates with extended assumptions beyond 2035. The user can alter the market share for each alternative LDV and HDV vehicle platform at the end of each decade. VISION interpolates alternative fuel vehicle sales for the intermediate years, with conventional ICE vehicles making up the remainder. The fuel economy of advanced vehicle technologies can be input as a ratio to the baseline ICE fuel economy. By default, the fuel economy for conventional ICE is set at 1.00, which can be altered to simulate improvements in conventional vehicles. Spark-ignition and diesel PHEV vehicles have two separate fuel economy ratios, representing their fuel economy during operation on an all-electric-range and while operating on liquid fuels.

Prices in constant 2005 dollars-per-gasoline-gallon-equivalent for eight fuels—gasoline, diesel, natural gas, E85, hydrogen Fischer-Tropsch diesel, biodiesel, methanol, and electricity—can be altered for each decade. Users can also specify decadal percentage values for the percentage of ethanol blended into gasoline and percentage of Fischer-

Tropsch process diesel and biodiesel in diesel fuels, as well as the percentage of miles flex-fuel vehicles will operate on E85 as opposed to conventional gasoline-ethanol blends. For cars and LTs, the user may also specify the year 2000 ICE price for a midsize sedan or small sport-utility vehicle, and the relative price of each alternative fuel vehicle platform for each decade. For example, VISION defaults model an MY2000 EV costing 2.7 times the default car price of $22,510, yielding an incremental price difference of $33,765; for MY2050, the cost ratio for EVs falls to 1.18, yielding an incremental price difference of $4,052.

Slight differences exist between procedures for modifying assumptions for LDVs and HDVs, but the process and inputs are generally similar. In addition, VISION accommodates more detailed scenario development by allowing users to modify figures in the background datasheets. In addition, the document Argonne National Laboratory, 2003 contains much more detailed information regarding the development of assumptions for the VISION model; however, this technical model description has not been updated as of this writing, and many of the assumptions described are outdated with respect to the current model.

UPDATING VISION WITH 2013 ASSUMPTIONS

As the current version of VISION is based on extended assumptions from AEO 2012, it was necessary to update several aspects of the VISION model in order to reflect more recent fuel economy and travel demand forecasts from AEO 2013. Notably, AEO 2013 features the more stringent fuel economy standards from the new CAFE program and lower VMT for light-duty vehicles. Three major updates were made to the default model assumptions to obtain a new AEO 2013 baseline. The first was to update the percentage of new vehicle sales for each car and light-truck technology, and the percent of new light-duty vehicle sales for light trucks, for each decade from 2010 through 2040, effectively updating the fleet in VISION. The second update was to adjust fuel economy for each vehicle type and decade. For each car and light truck technology (including conventional ICE and diesel engines), the ratio of its fuel economy in MPGe to the conventional vehicle baseline in VISION was calculated and entered into the model starting in 2009. For example, the fuel economy for conventional ICE cars sold in 2040 in AEO 2013 are forecast to be 52.23 MPG, compared with 38.61 MPG in the VISION baseline, so a ratio of 1.35 is entered for that decade. While a single, average fuel economy for plug-in hybrid vehicles is given in AEO, VISION requires separate entries for the fuel economy of plug-in hybrid vehicles: one while operating in charge-sustaining mode and another while operating in all-electric mode. EIA provided guidance for decomposing the fuel economy of plug-in hybrid vehicles, stating that they calculate the average using the following formula:

$$MPGe = (\%\ All\ Electric\ VMT * All\ Electric\ MPGe) + (\%\ Hybrid\ Mode\ VMT + Hybrid\ MPG)$$

with the assumption that short- and long-range plug-in hybrids have an all-electric VMT share of 21% and 58%, respectively (Nicholas Chase, 2013, personal communication). Since the fuel economy of hybrid vehicles is known, solving for the all-electric fuel economy is simple.

Finally, to ensure that VMT in 2040 matched the most recent forecasts, the appropriate growth factor for 2009 was used to obtain the 2.523 billion 2010 figure from AEO 2013. After

2010, annualized growth factors were applied for the periods 2011 – 2015, 2016 – 2020, 2020 – 2030, and 2021 – 2040, so that in the final year VMT matched the 3.718 billion VMT forecast.[2] Because VMT in VISION must be divided between cars and light trucks, it was assumed that the split was the same as estimated by VISION in updating the vehicle fleet. Economic and population projections cannot be changed in VISION and were not updated. Overall, updates to the model reduced emissions estimates in 2040 by 22.65% compared with the default VISION 2012 baseline for light-duty vehicles.

RUNNING THE VISION MODEL

The elasticities were applied to the adjusted VMT forecast within VISION for each of the policy scenarios. It was assumed that all TDM policies are introduced gradually, beginning in 2015. Because the CSTDM output groups cars and light trucks together, we assume drivers of both passenger vehicles will respond similarly to each policy; that is, a 20% reduction in total light-duty VMT represents a 20% reduction in VMT from cars and a 20% reduction in VMT from light trucks. The total change in VMT in 2040 and an annualized growth factor for the period of 2016 – 2040 was calculated. Modified growth factors were then input into the VISION model in order to calculate the life cycle emissions from transportation fuels used in light-duty vehicles. Commercial travel required a slightly different procedure, which was developed with assistance from Argonne National Laboratory (Anant Vyas, 2013, personal communication). For both medium- and heavy-duty vehicles, a final analysis year VMT and percentage reduction from the baseline is calculated. The relevant cell in the VISION truck worksheets was altered to reflect the reduction. Similar to light-duty vehicles, it is assumed that any percent reduction in VMT applies equally to all truck technologies.

V. RESULTS

The land-use scenario models a 10% increase nationwide in weighted job and population density, which would significantly curb auto-dependent development by moving a portion of population and demographic growth to existing city and town cores. Thus, the land-use scenario attempts to capture an effective transit-oriented development policy. In the California model, this was simulated by moving 2008 – 2035 household and employment growth that would have occurred in zones 3 to 12 miles from the nearest passenger rail transit station to zones within 3 miles of the station. In total, 4 million people, or 8.2% of the 2035 population, were moved. However, it is difficult to calculate what the exact effect would be at a national scale in terms of number of persons or jobs moved. The transit scenario doubles the amount of transit service available. Because transit and land-use policy would be coordinated in a maximally effective TOD scenario, these scenarios are combined. The pricing scenarios involve a 50% and 100% increase, respectively, in the marginal cost of driving. In order to capture a range of responses to these policy scenarios, three sensitivity analyses for each scenario are estimated: the middle-range uses the elasticity as output from the CSTDM model while the low-end decreases the elasticity by 25% and the high-end increases it by 25%.

Emissions reductions for the policy scenarios are shown in Figure 2. Only the VMT pricing scenarios provide significant reductions in emissions from the 2040 baseline. Increasing the marginal cost of driving by 50% decreases emissions 8% to 13% relative to the 2040 baseline, or 23% to 27% relative to 2000 levels. Doubling the marginal cost results in emissions levels lower than the 2040 baseline by 16% to 27%, a 29% to 38% reduction from 2000 levels. The land-use and transit scenario provides a maximum reduction of about 4.7% from the baseline, and a 20% reduction from 2000 levels. However, due to possible double-counting of trip reductions between these two scenarios, the low-end reductions of about 2.8% relative to the baseline or 18% relative to 2000 are probably more realistic for this scenario. The policy for the transit scenario was quite aggressive, doubling the amount of service provided. However, although the elasticity for increased transit service (-0.02) could be considered high compared with other studies, in absolute terms, it is quite low and little headway is made toward even the 50% reduction target. While the pricing scenarios reflect a change in travel behavior, this in itself may require supportive transit and land-use policies, as we would expect some of the travel reduction to come from mode shifts and changes in residential and employment location. Finally, it is worth noting that land-use and transit policies must be set at the local, or perhaps, regional level. Achieving even a 10% increase in density for the nation would require a very high degree of coordination to implement smart growth policies in jurisdictions across the U.S.

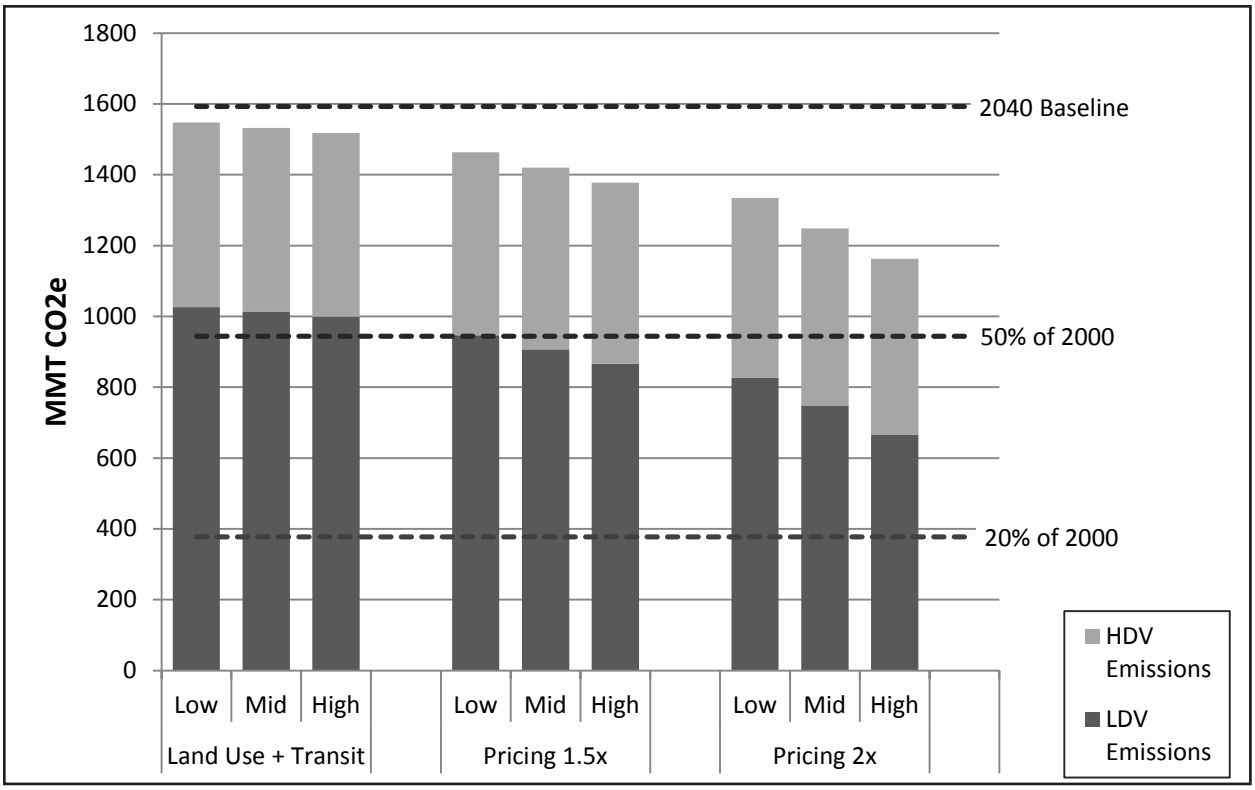

Figure 2. Scenario GHG Emissions

Figure 3 shows the necessary life cycle emissions reductions that would be necessary to meet 50% and 80% reduction targets by 2040. Again, only the pricing scenarios come close to achieving the goal of reducing emissions to 50% of 2000 levels. Additional reductions of about 40% are needed in most of the scenarios and, even under the most aggressive pricing scenario, lower-carbon vehicle technologies would need to be deployed at much higher levels than currently anticipated to reduce emissions by an additional 19%.

Commercial deliveries are relatively inelastic with respect to the cost of transportation, passing most of the increased cost on to consumers. Limiting the analysis to only passenger vehicles, it is clear that pricing would provide significant reductions. Figure 4 illustrates that under medium response to the pricing policy, the LDV fleet is able to reduce emissions by very nearly 50% by 2040 when pricing is doubled, and about 25% when pricing is increased by half. These results suggest that deeper reductions in emissions may be possible through pricing than have been found in other studies that may not have examined distance-based pricing measures at levels as high as in the current study (Deakin et al. 1996).

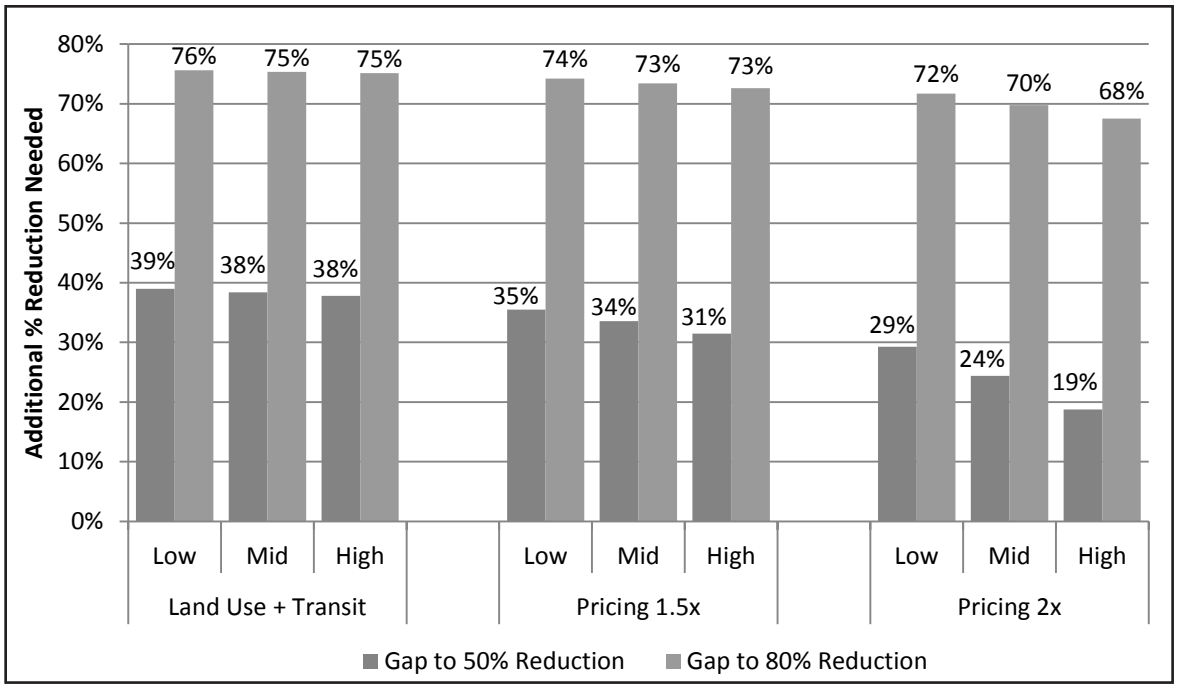

Figure 3. Additional Emissions Reductions Necessary to Meet 50% and 80% Reduction Target (Relative to 2000)

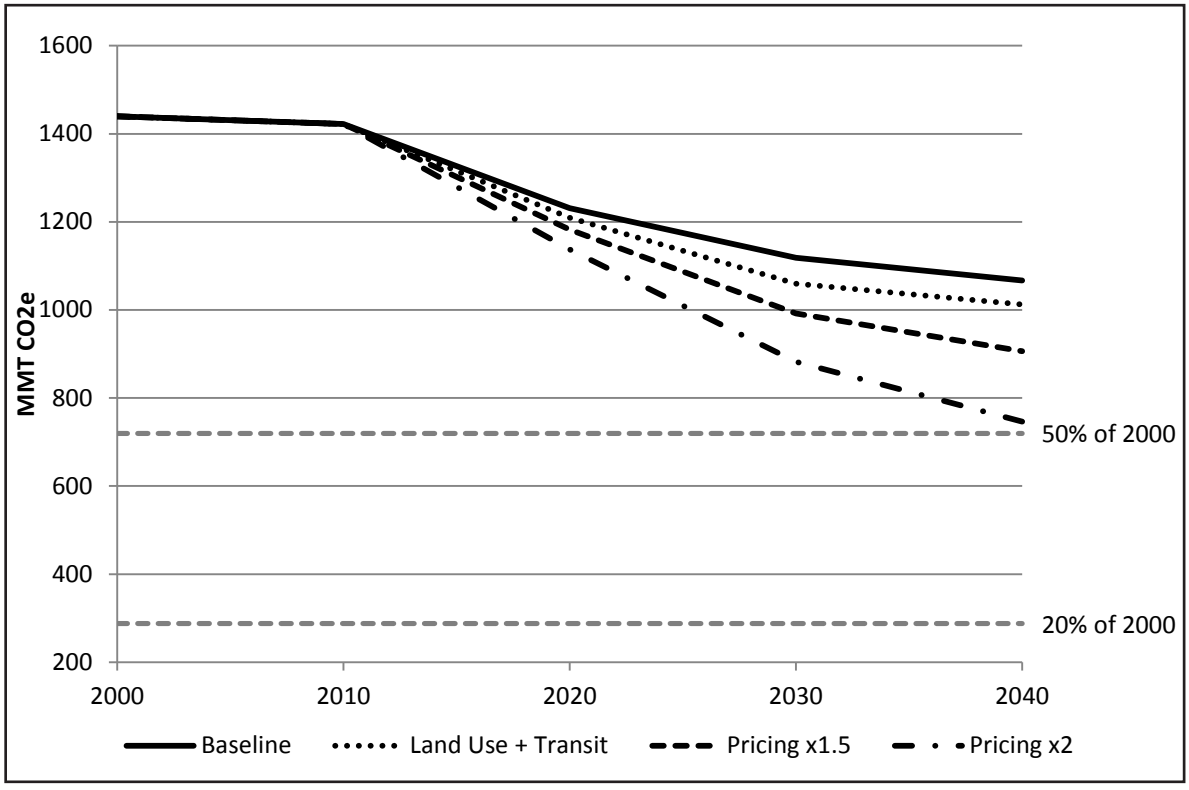

Figure 4. Total LDV Emissions for Individual Scenarios

Technological progress could be made on a variety of fronts, including increased use of electric drive and fuel cell vehicles, further increases in fuel economy, and increased use of natural gas in fleet vehicles, and increasing the amount of renewable biomass based diesel and ethanol blended into fuels. However, each of these technologies faces well documented technical, economic and political barriers, discussed in the literature review above and beyond (National Research Council 2011). Rather than looking at the possibilities for each such option, one way to look at how much technological progress is necessary is to examine the per-mile emissions reductions needed to meet climate policy targets. Figure 5 illustrates the additional percent-per-mile efficiency necessary to meet a 50% target, relative to 2000 for light-duty, medium- and heavy-duty, and all fleet vehicles.

Since VMT differs between each scenario, the target life cycle emission rate (in grams of CO_2e per mile) differs as well. For light-duty vehicles, improvements of up to 30% are necessary to reduce emissions by 50% in 2040 for the land-use and transit scenario. Increasing the per-mile cost of driving by 50% leaves a gap in per-mile GHG reductions of 17% to 24%, and doubling the per-mile cost of driving could meet or exceed GHG performance goals at least for LDVs. Under both pricing scenarios, the need for improvements that increase carbon efficiency is greatly diminished by substituting behavioral change for better technology.

The need to reduce per-mile emissions from heavy-duty vehicles is relatively constant at about 56%. This is mainly due to continued growth in large trucks making intercity deliveries. This result meets our expectations, as most freight travel should be largely invariant with respect to land-use policies. In each individual scenario, the quantity of emissions from medium- and heavy-duty vehicles increases over 2000 levels by 15% to 18%. Moreover, the share of emissions from freight and delivery vehicles increases from approximately 24% in the baseline to nearly 34% in the most aggressive (Pricing 2x, High elasticity) scenario, with improvements in passenger-vehicle performance “subsidizing” the lack of improvements for freight. This highlights the need to consider more stringent fuel economy standards and increased use of renewable, lower-carbon fuels in freight transportation.

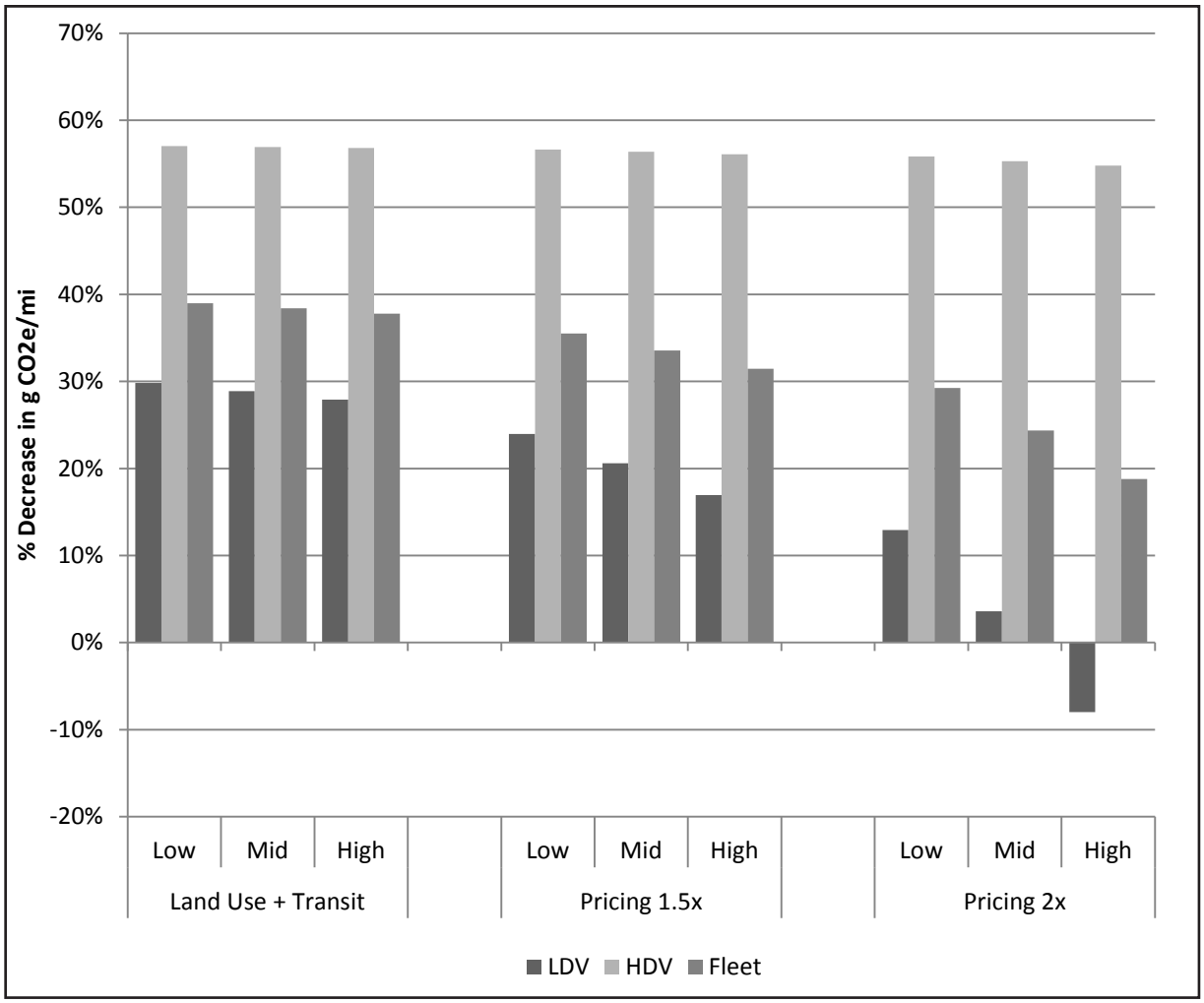

Figure 5. Additional Percentage Decrease in Per-Mile Emissions Necessary to Reach 50% Reduction Target (Relative to 2000)

VI. CONCLUSIONS

The scenario analysis above suggests that, relative to 2000 levels, only the VMT pricing scenarios provide significant reductions in emissions from the 2040 baseline. Increasing the marginal cost of driving by 50% decreases emissions 8% to 13% relative to the 2040 baseline, or 23% to 27% relative to 2000 levels. Doubling the marginal cost results in emissions levels lower than the 2040 baseline by 16% to 27%, a 29% to 38% reduction from 2000 levels. The land use and transit scenario provides a maximum reduction of about 4.7% from the baseline, and a 20% reduction from 2000 levels. These results show the difficulty in meeting targets for GHG reductions in the transportation sector. Life cycle reductions of 50% from the 2000 baseline will require aggressive technology policies supplemented with pricing policies. The latter will likely also require supportive land use and transit measures to mitigate the impact of increased costs of travel.

These results are sector-specific and it is important not to view each sector of the economy in isolation. For example, cleaner electricity, generated from renewable resources can benefit the transportation sector by reducing the life cycle GHG emissions from PHEVs and BEVs. But reducing emissions in other sectors even further may mean the transport sector does not need to independently meet the 50% target. Mobility is highly valued by society and as these results show, even doubling the price of travel does not achieve the targets (except in our most aggressive scenario). Moreover, increasing the cost of driving would likely prove to be politically difficult in the U.S. The price of gasoline, while substantially lower than other developed countries, is perceived as too high. Fuel taxes have remained constant since the early 1990s, are not pegged to inflation, and revenues are significantly offset by increasing vehicle efficiency. Although some pilot studies have investigated VMT fees, nowhere has a distance-based fee for passenger road transport actually been implemented.

Freight transportation is problematic. It is difficult to achieve reductions via mode shifting (Noland and Wadud 2009, 84-99). While new standards will require reductions in GHG emissions from medium and heavy-duty trucks, more aggressive standards and technological advances will be required to achieve significant reductions. Renewable fuels may be one approach to achieve further reductions in GHG emissions from these vehicles.

The results of this study are consistent with those of other “gap” analysis. Most other analyses find that a combination of policies, both technology and behavioral, are needed to achieve reduction targets. The results here are no different, and this is an important policy conclusion to emphasize. One major caveat to this study is that air travel was not modeled; some analysis suggests that if reductions in air travel are not achieved that this one sector could account for a large share of total emissions by 2050, assuming other reductions are achieved (Bows and Anderson 2007, 103-110). In the end both a multi-policy and multi-sector approach will be needed to meet reduction targets that maintain global temperatures at no greater than a 2°C increase.

APPENDIX A: THE CALIFORNIA ACTIVITY-BASED TRAVEL DEMAND MODEL

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Farzad Alemi

Giovanni Circella, Ph.D.

Recent advances in operational activity-based models (ABMs), which are capable of representing the travel effects of many transportation demand management (TDM) strategies, allow for a closer investigation of the direction and magnitude of biases that may result from the failure to account for the interaction of combinations of TDM. In the current study, California's ABM (known as the California Statewide Travel Demand Model, or CSTDM) is applied to simulate the travel effects of land use, transit, and auto pricing policies.

METHODS

The CSTDM, like other ABMs, is characterized by its use of a disaggregate framework that enables a more complete and consistent representation of microeconomic theory throughout the model system. The probability of an individual traveler selecting a given alternative is a function of his or her socioeconomic characteristics and the relative attractiveness of the alternative. Microsimulation is the mathematical technique used to track individuals' activities and travel throughout the model system that represents a typical day. Activities that individuals need to perform are linked to travel-related choices based on data from four surveys. Each person/household is assigned to a transportation analysis zone. Travel time and costs are extracted from the road and transit networks. Tours are the unit of analysis in the model. Four California travel surveys were assembled to estimate the parameters for the sub-models implemented in the CSTDM: the California Department of Transportation Statewide Travel Survey (2000), the San Diego Association of Governments Travel Survey (2006), the Southern California Association of Government Travel Survey (2001), and the Metropolitan Transportation Commission Bay Area Travel Survey (2000). All individuals and their socioeconomic characteristics are generated through a statistical process, known as a population synthesis, based on the U.S. Census Public Use Microdata Sample (PUMS). The CSTDM requires employment data for workers by both industry and occupation, which was obtained from the Census Transportation Planning Package (CTPP), PUMS, California Employment Development Department, and the Longitudinal and Household Dynamics (OnTheMap) data.

Transportation supply is represented in the CSTDM by a transportation analysis zone system (geographic units of analysis) and roadway and transit networks. The following modes are represented in the CSTDM: auto single-occupant vehicle (SOV), auto high-occupancy vehicle (HOV) 2-person, auto HOV 3+-person, bus, rail, bicycle, walk, air, light

commercial vehicle, single-unit truck, and multiple-unit truck. The road network represents all freeways, expressways, and most arterial roadways explicitly, with collector and local roads mostly represented by zone-centroid connector links. The transit network combines explicitly coded fixed guideway transit, including all air and rail lines and services, with algorithmically derived local transit (bus) service. A simplified model is used for local bus transit to give level of service times and costs, based on road network speeds, land-use variables, and transit operator service measures. Observed data (collected through the Google Transit platform) were used to develop the model. Networks are developed for the following time periods: early off-peak (3 AM to 6 AM), morning peak (6 AM to 10AM), midday (10 AM to 3 PM), PM Peak (3 PM to 7 PM), and off-peak late (7 PM to 3 AM). Traffic is assigned to the network using static assignment processes. Modeled roadway volumes were validated against observed count data for the year 2008. For detailed information on the CSTDM see (ULTRANS and HBA Specto 2011b; ULTRANS and HBA Specto 2011c; ULTRANS and HBA Specto 2011a; ULTRANS and HBA Specto 2011; ULTRANS and HBA Specto 2012b; ULTRANS and HBA Specto 2012a).

SCENARIOS

The base or business-as-usual scenario for the future year 2035 is based on demographic projections from seventeen California's MPOs, four rural transportation planning agencies (RTPAs), and the California Department of Finance as of August 2011. The zones and network system were expanded to 5,421 zones and 248,424 roadway links in 2035 to support the expansion of population and employment from 2008. Future roadway and transit projects were obtained from regional transportation plans developed by California MPOs and RTPAs prior to August 2011. Future rail transit information was also compiled from transit organizations' documentation, such as, Amtrak, MPOs, and cities.

Changes were made to the 2035 base scenario inputs as described in Table 6 to create transit, land-use, and VMT pricing scenarios. In the vehicle pricing scenario, per-mile vehicle operating costs doubled from $0.14 to $0.28 for passenger and light-duty vehicles. The transit scenario halves existing base headways and doubles local bus service. In the land-use scenario, growth in households and employment from 2008 to 2035 in zones within 3 to 12 miles outside of the nearest passenger transit station (light and heavy rail) is moved to zones within 3 miles of that transit station (4 million people were moved or 8.2% of the 2035 population). Figure 6 illustrates the development of the land use scenario in the San Diego and San Francisco regions. The weighted density is used to compare relative densities in the scenarios and regions. Average density cannot be used to describe the land-use scenario because total population stays the same (both in California and the five major regions); only household populations are moved closer to transit stations and city centers. The following calculations describe the weighted density measure:

$$(1) \quad Density_i = \frac{population_i}{square\ miles_i}, for\ Zone\ i$$

(2) $$Weight_i = \frac{density_i}{\sum_J density_j}, for\ Zone\ i, where\ i\ in\ region\ J$$

(3) $$Weighted\ Regional\ Density = \sum_J (density_j * weight_j), for\ region\ J$$

Table 6. Percentage Change in Individual and Combined California Scenarios from 2035 Base Case

2035	Transit Service	Per-Mile Auto Operating Costs	Weighted Density
Transit	100%	-a	--
Land use	--	--	9.50%
VMT pricing	--	100%	--

[a] - is no change.

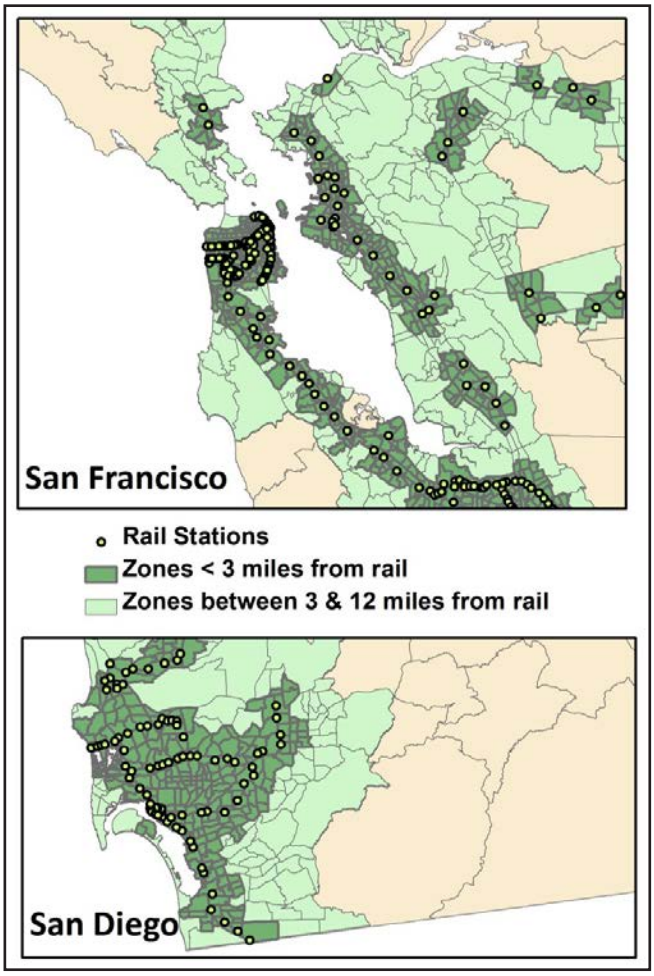

Figure 6. Example of Land-Use Scenario in San Francisco Bay Area and San Diego

Table 7 describes key attributes of the state.

Table 7. Key Geographic Attributes for California

Attributes	California
2008 transit-to-work mode share	3.8%
2008 average density per square mile	7,805
2008 population (millions)	38.4
Total population growth (2008 – 2035)	26%

ABBREVIATIONS AND ACRONYMS

AEO	Annual Energy Outlook
ANL	Argonne National Laboratory
ARRA	American Recovery and Reinvestment Act
BEV	Battery Electric Vehicle
CAFE	Corporate Average Fuel Economy
CSTDM	California Statewide Transportation Demand Model
DOE	U.S. Department of Energy
EIA	Energy Information Administration
EISA	Energy Independence and Security Act
EPA	U.S. Environmental Protection Agency
EV	Electric Vehicle
FCV	Fuel Cell Vehicle (Hydrogen)
GHG	Greenhouse Gas
HDV	Heavy-Duty Vehicle (trucks with a gross vehicle weight of greater than 20,001 pounds)
HEV	Hybrid Electric Vehicle
ICE	Internal Combustion Engine
LDV	Light-Duty Vehicle (cars and light trucks)
LT	Light Trucks (two-axle, four-tire trucks with a gross vehicle weight less than 10,000 pounds)
MDV	Medium-Duty Vehicle (trucks with a gross vehicle weight of 10,001 to 20,000 pounds)
PHEV	Plug-In Hybrid Electric Vehicle
RFS	Renewable Fuel Standards
RVO	Renewable Volume Obligation (under renewable fuel standards)
TDM	Transportation Demand Management
VMT	Vehicle Miles of Travel

ENDNOTES

1. This budget range is based on several proposals for the international distribution of burden associated with abatements sufficient to reach a less-than-50% probability of global temperature rise within 2°C relative to the pre-industrial period—a figure more than 100 countries have adopted as the limit before climate change becomes catastrophic (Meinshausen et al. 2009).

2. The mid-decade forecast for 2015 was included so that policy scenarios could be introduced starting in 2016.

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