MOVING CALIFORNIA FORWARD

HOW SMART GROWTH CAN HELP CALIFORNIA REACH ITS 2030 CLIMATE TARGET WHILE CREATING ECONOMIC AND ENVIRONMENTAL CO-BENEFITS

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ENERGY INNOVATION
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CALTHORPE
ANALYTICS

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ENERGY INNOVATION

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Calthorpe Analytics is an urban planning and analysis firm founded on 30 years of leadership in regional planning and analysis. The firm has led some of the largest and most complex planning efforts in North America. Calthorpe Analytics' planning and modeling work is grounded in a comprehensive understanding of the relationship between planning and infrastructure decisions and the fiscal, environmental, public health, and livability challenges facing states, regions, and cities across the globe.

PREFACE

In September, we released a summary of this research. This is the technical documentation for the work. The Summary given here includes a handful of small changes from the first version that was released.

(Cover photo: iStock)

SUMMARY

This past spring, Governor Jerry Brown set a goal of reducing California's carbon emissions in 2030 by at least 40% below the 1990 level of emissions (Executive Order B-30-15). This target, now reflected in the proposed legislation of Senate Bill 32, is both scientifically grounded and feasible. But achieving the target will require California to intensify its policy efforts across all sectors of the economy. This study analyzes the role of land use policy in achieving the emissions target. **Our results show that implementation of smart land use policy, in combination with technological advances in the energy sector, will be critical for the state to achieve its ambitious 2030 decarbonization target.**

We recommend that the California Air Resources Board (CARB) strengthen emissions reduction targets under SB 375 (California's regional land use planning law) as part of a 2030 Scoping Plan and complement these targets with substantial funding to support cities and regions so they can successfully implement the target-compliant land use plans they are tasked to develop. Along with reducing emissions, smart growth also delivers an impressive array of co-benefits: cleaner air, improved public health outcomes, lower water use, cost savings for households, reduced dependency on oil, more efficient provision of public infrastructure, reduced congestion, and the preservation of natural and working lands, which provide carbon sequestration and other ecosystem services. Smart growth will help expand the supply of housing most in demand. Increasingly, people want to live closer to work, in walkable neighborhoods that are well served by transit.[1]

Walkable, mixed-use places like San Diego's Gas Lamp District are in high demand. (Photo source)

Land use patterns and transportation investments play a fundamental role in how far we travel and how we get from home to work, school, shopping, recreation, and other activities. The spatial layout of neighborhoods determines whether we have the option of walking, biking, and taking public transit, or whether we must drive. Smart growth that coordinates land use and transportation planning can significantly reduce dependence on cars for most travel. Enabling a variety of travel mode options increases travel efficiency, reduces congestion, and improves overall mobility. This is the fundamental cause-effect dynamic at work in the results that follow.

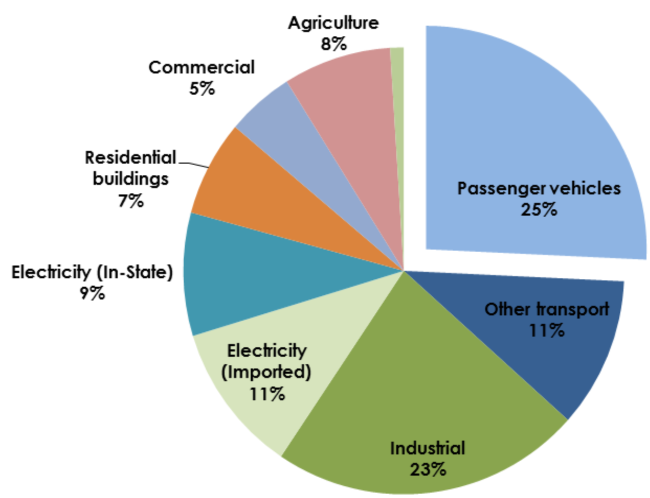
This dynamic is being put into practice in cities and regions across California. Statewide, the number of trips people take by transit, walking, and biking has doubled between 2000 and 2012.[2] In Southern California, cities and the regional planning and transit agencies have collaborated and taken bold steps to rapidly build up a comprehensive transit system. These efforts are steering more housing and job

[1] Nelson, Arthur C. (Urban Land Institute). 2011. *A New California Dream: How Demographic and Economic Changes May Shape the Housing Market*.

[2] California Department of Transportation. 2013. *2010-2012 California Household Travel Survey – Final Report*.

growth to new and existing transit-connected locations. The Bay Area recently saw the nation's biggest reduction in the share of people commuting alone by car.[3] These changes are cutting emissions by reducing reliance on cars for everyday travel needs. This is a crucial step toward reducing emissions from passenger vehicles, the top source of carbon emissions in California (as shown in Figure ES-1).

Figure ES-1. California GHG Emissions by Sector in 2013[4]



THE ROLE OF LAND USE IN REDUCING EMISSIONS

Land use is a critical element of California's climate change efforts. Urban form shapes travel demand, and the quantity of passenger vehicle miles traveled (VMT) is a major determinant of California's carbon emissions. To this end, our study utilizes Calthorpe Analytics' RapidFire model[5] in combination with the Energy + Environmental Economics (E3) California Pathways study ("the E3 study"),[6] completed in April 2015. The E3 analysis provides the energy technology specifications, as well as assumptions about variables such as future population and energy prices, that are needed as inputs for RapidFire. We align with the E3 work because it is a careful study providing comprehensive energy coverage, and it was commissioned by state policymakers to inform the setting of a 2030 carbon emissions reduction goal.

The E3 study explores a variety of 2030 scenarios, building on low-carbon technologies currently available in the marketplace. The fastest emissions reduction pathway mapped in the E3 study falls short of the 2030 goal. We test a hypothesis that smarter land use could make the difference in meeting or surpassing the 40% reduction. Our results indicate that smart growth can indeed serve California in achieving the 2030 goal while also yielding other valuable environmental, fiscal, and public health co-benefits.

[3] U.S. Census Bureau. 2015. *Who Drives to Work? Commuting by Automobile in the United States: 2013*.

[4] 2013 are most recent data available. Sourced from: California Air Resources Board. 2015. *California Greenhouse Gas Inventory, 2015 Edition*.

[5] Calthorpe Analytics. Technical Summary available at www.calthorpeanalytics.com

[6] Energy + Environmental Economics, Inc. 2015. *California Pathways + GHG Scenario Results*.

Table ES-1 summarizes the land use inputs applied in the E3 study and the scenarios developed for this study.

Table ES-1: Land Use Scenarios Defined

Study	Scenario Name	Description
E3 California Pathways	Baseline	Representative of past trends, not taking into account actions under SB 375.
	Smart Growth	The main smart growth scenario used by E3 assumes significant VMT savings as compared to the Baseline land use/VMT applied with their Reference Case scenario. E3 also developed a more aggressive smart growth scenario used for sensitivity testing, but it was not applied in combination with their Early Deployment scenario.
Energy Innovation/ RapidFire	Past Trends	A continuation of past trends, not taking into account the impact of SB 375.
	Current Plans	Potential trajectory given current planning and policy actions in line with SB 375.
	More Compact	Stronger smart growth policy that prioritizes focused development in coordination with transit investments, and meets demand for housing in walkable, accessible communities.
	Infill Focus	Strongest smart growth policy, building upon the More Compact scenario with greater focus on infill. Going forward, 85% of new housing and jobs are added within existing urban boundaries.

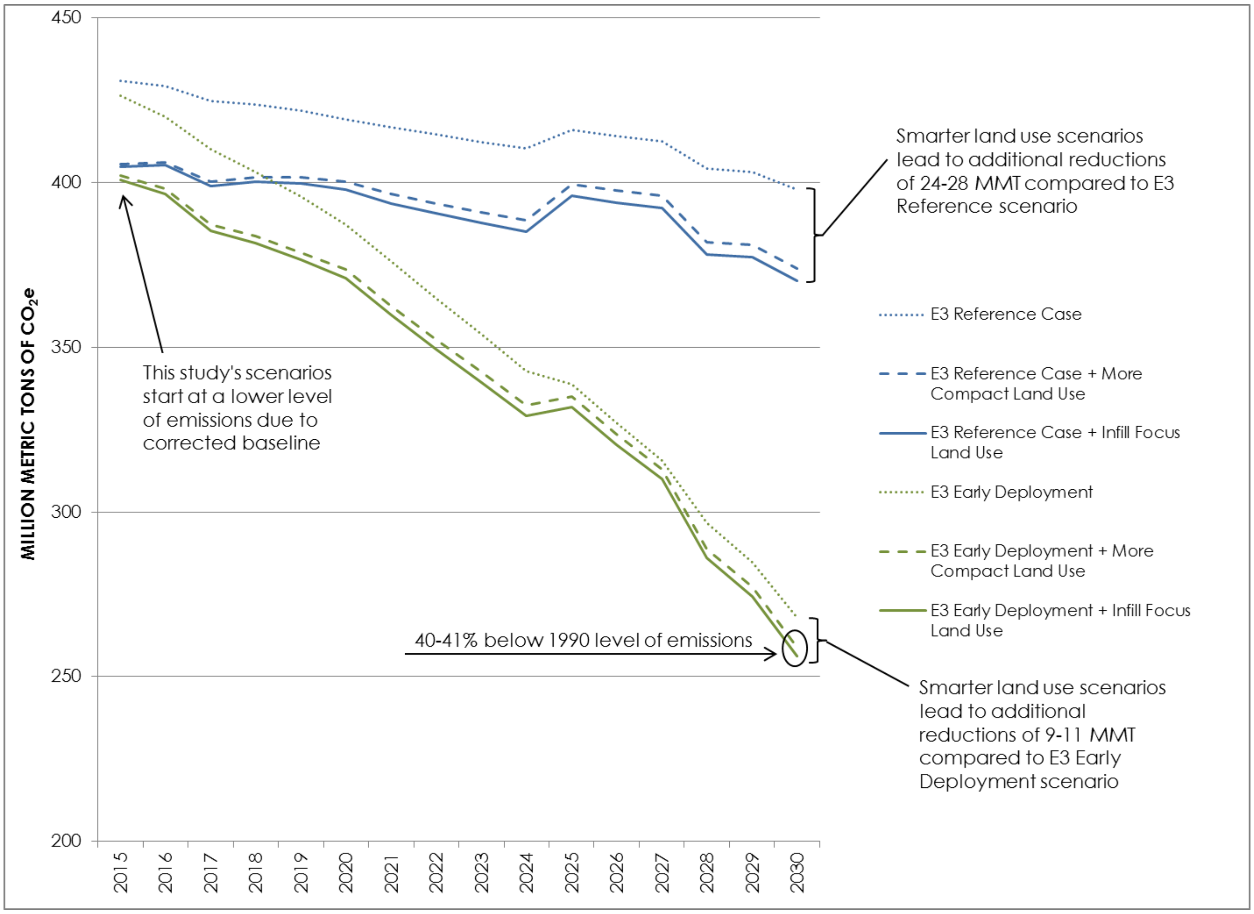
The land use scenarios are combined with two sets of energy technology assumptions from the E3 study:

1. **E3 Reference Case:** this scenario forecasts the technological pathway expected given current policy (e.g., 33% Renewable Portfolio Standard). The E3 Reference Case scenario applies the E3 Baseline land use assumption (described in Table ES-1). The scenario produces an economy-wide reduction equal to 8% below 1990 emissions by 2030.

2. **Early Deployment:** this is the deepest-reduction pathway to 2030 developed in the E3 study. It assumes aggressive technology deployment across sectors (e.g., 60% renewable electricity in 2030). Regarding land use, E3 assumes their Smart Growth VMT projection. The Early Deployment scenario reaches 38% below the 1990 level of carbon emissions in 2030.

Figure ES-2 brings these energy and land use assumptions together, showing the deeper reductions attributable to land use. The dotted lines show the original emissions reduction pathways traced by E3's Reference Case and Early Deployment scenarios. The dashed and solid lines illustrate further emissions reductions achievable with our More Compact and Infill Focus scenarios, respectively, in combination with the E3 energy technology assumptions.

Figure ES-2. Updated Smart Growth Analysis Shows Statewide Reductions Reaching 40-41% Below 1990 Emissions in 2030



In combination with the E3 Early Deployment scenario, the RapidFire smart growth scenarios yield additional reductions of 9-11 million metric tons (MMT) of carbon dioxide equivalent (CO_2e). This leads to statewide reductions of 40-41% below 1990 emissions, in line with the proposed 2030 target. The additional avoided emissions stem primarily from differences in passenger VMT, due to newer data and the smart growth actions modeled in this study.[7] Some savings are also attributable to reduced building energy demand. The results demonstrate that smart land use is integral to achieving California's 2030 decarbonization targets.

[7] The graph shows the results of two of E3 scenarios as originally estimated, and then updates these with the More Compact and Infill Focus scenarios developed for this study. E3's study began before a more recent state transportation evaluation known as EMFAC 2014 was completed. E3 took steps to try to correct for this, but their Baseline VMT levels – those expected under current conditions without additional smart growth action – still appear to be too high. As the graph illustrates, in correcting for the higher VMT, baseline emissions are reduced to levels that are lower than is likely today. The statewide inventory shows a total of 459 MMT of CO_2e in 2013, the most recent year reported. We hypothesize that the E3 study's inflated VMT was offset by assumptions on fuel economy. With respect to interpretation of smart growth impacts, this means that our estimates of avoided carbon emissions are likely on the conservative side. Better vehicle fuel economy reduces the benefit of each mile of travel demand avoided.

SIGNIFICANT CO-BENEFITS

Smart land use does more than "close the gap" in achieving target carbon reductions. Compact land use patterns, developed in coordination with transportation investments, will meet Californians' increasing demand for housing in walkable, transit-accessible communities and create valuable co-benefits. We quantify these co-benefits given current policy (assuming the E3 Reference Case energy assumptions). Table ES-2 summarizes the benefits by 2030 of the Current Plans, More Compact, and Infill Focus scenarios as compared to the Past Trends scenario. Cumulative impacts reflect results from 2015 to 2030, while annual impacts reflect results in 2030.

Table ES-2. Co-Benefit Impacts in 2030, Annual and Cumulative

	Current Plans	More Compact	Infill Focus
Economic impacts quantified (2015$)			
Household cost savings[a]			
Cumulative to 2030	$79 billion	$196 billion	$250 billion
Annual per average household in 2030	$600	$1,600	$2,000
Avoided public health costs[b]			
Cumulative to 2030	$2.6 billion	$6.4 billion	$8.2 billion
Annual in 2030	$320 million	$850 million	$1,040 million
Infrastructure cost savings[c]			
Cumulative to 2030	$9.3 billion	$12.4 billion	$18.5 billion
Environmental impacts quantified			
Criteria pollutant emissions avoided[d]			
Cumulative to 2030	217,000 tons	532,000 tons	686,000 tons
Annual in 2030	19,000 tons	50,000 tons	61,000 tons
Residential water savings[e]			
Cumulative to 2030	540,000 acre-feet	1.28 mil acre-feet	1.59 mil acre-feet
Annual average per new household in 2030	9,300 gallons	21,900 gallons	27,300 gallons
Land conservation[f]			
Cumulative to 2030	270 sq mi	490 sq mi	700 sq mi

[a] Household costs include those for auto fuel, ownership, and maintenance; and residential energy and water.

[b] Public health costs include those related to air pollutants from passenger vehicle transportation, including cases of mortality; respiratory-related ER visits; upper, lower, and acute respiratory symptoms; exacerbated asthma attacks; heart attacks; hospitalization from respiratory and cardiovascular illness; and lost work days.

[c] Infrastructure costs include one-time capital costs for building local roads, water, and sewer infrastructure; and ongoing annual operations and maintenance costs.

[d] Criteria pollutant emissions include NO_x, SO_x, CO, VOC, PM-2.5, and PM-10 from passenger vehicles.

[e] Water use includes indoor and outdoor use, with outdoor irrigation being the primary cause for variation.

[f] Land conservation refers to the savings of undeveloped "greenfield" land, including open space and agricultural lands.

Smarter land use patterns beyond the Current Plans scenario would save households $1,000 to $1,400 annually (2015 dollars), mostly through lower auto-related spending. In addition to household savings, the costs borne by cities to build and maintain local roads, sewers, and water infrastructure is also reduced significantly, with $12-$18.5 billion in cumulative savings through 2030 due to more compact growth. Avoided health costs related to pollution from passenger vehicle travel are also substantial, with cumulative savings of $2.6-$8.2 billion through 2030.[8] The benefits of smarter land use build over time and will be even larger in 2035 and 2050.

POLICY IMPLICATIONS

In addition to bolstering the case for the proposed 2030 emissions goal, this report also performs two other analyses that are relevant to current policy questions. These analyses are related to SB 375, the state's pioneering land use law, and the target to use 50% less oil for transportation, one of the "pillar" goals that California Air Resources Board (CARB) is working on to build up a set of actions to meet the 2030 target.

The CARB is currently considering whether to deepen future SB 375 targets. Our results indicate that stronger targets, combined with funding and implementation support, could be a deciding factor in achieving the 2030 goal. The More Compact and Infill Focus scenarios would yield reductions below the 2014 VMT per capita level of 9-12% in 2030 and 12-15% in 2035.

Our analysis of the potential for oil use reductions for transportation in 2030 pertains to the passenger vehicle segment, which makes up three-quarters of all on-road emissions. Our analysis indicates that a 2% reduction from today's total VMT levels would accomplish a 50% reduction in oil use (using the E3 Early Deployment scenario for other assumptions). Under the Infill Focus scenario, total VMT in 2030 rises by about 1% from today's level while population increases by 14%. Though this reduction is slightly higher than that of any of the scenarios we model, we would expect such an outcome to be achievable in combination with other evolving mobility options, such as ride-hailing companies (e.g., Uber, Lyft), micro-transit (private companies operating like public transit agencies over smaller areas, e.g., Chariot), bike sharing and e-bikes, and investments in safe active transportation infrastructure (i.e., to support cyclists and pedestrians). These emerging transportation choices fit well with more compact and mixed land use patterns where homes, services, and jobs are nearby.

[8] Avoided health cost assumptions developed by Environmental Defense Fund/American Lung Association in California/Tetra Tech for their recent study, *Driving California forward: Public health and societal economic benefits of California's AB 32 transportation fuel policies* (May 2014).

CONCLUSION

Building mostly within our existing urban boundaries won't be simpler, but it will pay off with economic, environmental, and social benefits. The smarter growth patterns modeled in this study deliver more transportation choices, better mobility, and an upgraded quality of life for millions of Californians. This report quantifies the carbon emissions reductions and a selection of the co-benefits associated with smarter development. The land use patterns studied here could lead to even larger carbon emissions reductions than estimated because they will also preserve more land in California for carbon sequestration.

More focused growth is easier to serve with quality public transit, like this Bus Rapid Transit line, the San Bernardino express. (Photo source)

In conjunction with technological innovation, comprehensive land use planning is crucial to meeting the larger goals for economy-wide emissions reduction and reducing oil consumption by 50%. CARB should set stronger SB 375 goals that are consistent with the Governor's Executive Order to reduce statewide carbon emissions 40% below 1990 levels by 2030. CARB should also set stronger requirements for smart growth actions by local governments to qualify for funding from auction revenues.

California's population is expected to hit 50 million by 2050, up from 39 million today. As the state's population and economy expand, it is vital to think about future growth patterns and their implications. Land use patterns, once established, are long-lasting and can be costly to reverse or retrofit. Rather than emphasize the downside of past patterns, this report prefers to focus on the potential upside to redoubled smart growth efforts. There is a golden growth opportunity to be seized. The state should further advance its efforts to encourage patterns that will help the state meet its health, climate, energy, water, and fiscal challenges. The world's cities, like California's, are surging with energy, drawing new residents, and driving innovation and growth. California, as a policy leader and America's most urbanized state, is poised to help advance and benefit from this new age of enlightened urbanism.

CONTENTS

LIST OF ACRONYMS

CARB: California Air Resources Board

CEC: California Energy Commission

CEQA: California Environmental Quality Act

CEUS: Commercial End-Use Survey

E3: Energy + Environmental Economics

EIA: Energy Information Administration

HQTA: High Quality Transit Area

LDC: Land Development Category

LOS: Level of service

MPO: Metropolitan planning organization

MTC: Metropolitan Transportation Commission

PDA: Priority Development Area

RASS: Residential Appliance Saturation Study

RTP: Regional Transportation Plan

SANDAG: San Diego Association of Governments

SCAG: Southern California Association of Governments

SCS: Sustainable Communities Strategy

TPA: Transit Priority Area

VMT: Vehicle miles traveled

1. INTRODUCTION

This past spring, Governor Jerry Brown set a goal of reducing California's carbon emissions in 2030 by at least 40% below the 1990 level of emissions (Executive Order B-30-15). This target, now reflected in the proposed legislation of Senate Bill 32 (SB 32), is both scientifically grounded and feasible. But achieving the target will require California to intensify its policy efforts across all sectors of the economy. This study analyzes the role of land use policy in achieving the emissions target. **Our results show that implementation of smart land use policy, in combination with technological advances in the energy sector, will be critical for the state to achieve its ambitious 2030 decarbonization target.**

Land use patterns and transportation investments play a fundamental role in how far we travel and how we get from home to work, school, shopping, recreation, and other activities. The spatial layout of neighborhoods determines whether we have the option of walking, biking, and taking public transit, or whether we must drive. Smart growth that coordinates land use and transportation planning can significantly reduce dependence on cars for most travel. Enabling a variety of travel mode options increases travel efficiency, reduces congestion, and improves overall mobility. This is the fundamental cause-effect dynamic at work in the results that follow.

This report presents new evidence on the substantial environmental, economic, and livability benefits of more efficient land use patterns. On the environmental front, strong action to promote smarter growth will not only reduce auto travel to help California achieve its climate goals, but save energy and water, improve air quality, and preserve critical open spaces and agricultural lands. There is a strong economic component to land use choices as well. Successful cities are magnets for talented people. This infusion of human capital drives innovation and productivity gains; yet, only well-coordinated planning for compact, mixed-use, transit-oriented development will provide sustainable mobility options amidst a thriving economy. Alleviating the need to travel by car, in turn, lightens a significant cost burden on California households. Awareness of this and the many other connections between land use patterns and livability is growing. Indeed, throughout California and the U.S. the demand for compact, walkable neighborhoods is on the rise.[9]

However, demand alone is not enough to bring about smarter growth and create sustainable communities. The land use scenarios created and analyzed for this report emphasize the critical role of regional and local land use plans that promote and enforce compact growth patterns in California. The Governor's ambitious 2030 targets will only be achieved with more emphasis on smart growth. Land use strategies are fundamental in reducing emissions from transportation and building energy use. Once established, land patterns are long lasting and can be costly to reverse or retrofit. Hence, it is critically important to set and reinforce patterns that will contribute to meeting state climate, energy, water, and fiscal challenges.

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[9] The National Association of Realtors 2013 Community Preference Survey indicates that 60% of respondents prefer neighborhoods with a mix of homes, stores, and businesses that are within walking distance over those requiring more driving. (NAR 2013) See http://www.realtor.org/sites/default/files/reports/2013/2013-community-preference-analysis-slides.pdf.

This report is organized as follows. Section 2 describes the research question that motivates this study, and gives a preview of the results of the analysis. As further background, Section 3 explores the many positive steps that are currently being taken by the state to reduce car dependency and associated climate, energy, and health impacts. Section 4 describes the study itself, including a discussion of the inputs and methodology and a presentation of results. Sections 5 and 6 present the recommendations that follow from this analysis and next steps for research. A concluding section resituates the main findings of the report.

2. RESEARCH QUESTION

This study evaluates the role of more efficient growth patterns in meeting California's bold climate and energy targets. The analysis will inform three active areas of policymaking:

I. The 2030 statewide cap on emissions that would cover the entire economy.
II. Policies to accomplish a 50% reduction in oil use for transportation.
III. The updating of regional emissions reduction targets under Senate Bill 375 (SB 375).

2030 Cap

In April 2015, Governor Brown issued an Executive Order calling for California's statewide carbon emissions to fall to 40% below 1990 emissions by 2030. Underlying this new 2030 goal was research commissioned by the California Energy Commission (CEC) and the California Air Resources Board (CARB) to analyze cost-effective carbon emission mitigation options across the state's economy. While the work, conducted by the technical consultancy Energy + Environmental Economics, Inc. (E3), includes some assessment of smart growth and land use-based opportunities, they could not cover every possibility in depth given the ambitious scope of their research. This study looks more deeply at the potential for more efficient growth patterns to yield cost-effective carbon emission reductions that also offer valuable co-benefits, from land and natural resource conservation to lower household costs and local infrastructure cost burdens.

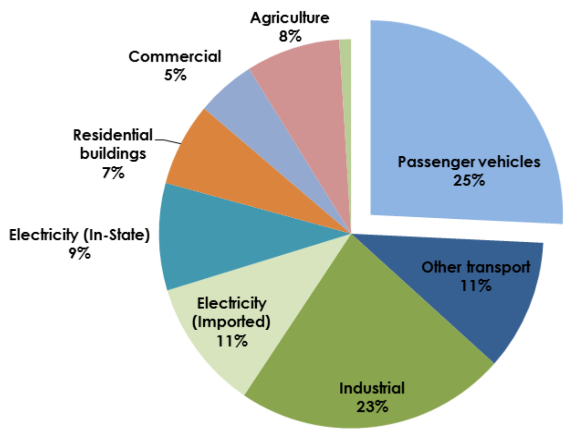
50% Reduction in Oil Used for Vehicles

The California Air Resources Board has identified a 50% reduction in the oil used for motor vehicles as one of the "pillar" goals to help meet the statewide 2030 cap. We analyze how smarter growth patterns can contribute to achieving this goal. We evaluate the reduction in vehicle miles traveled (VMT) that would lead to a 50% reduction in oil for passenger transportation under the vehicles and fuel scenarios mapped out by E3.

SB 375 Target Setting

California's SB 375 (the "Sustainable Communities and Climate Protection Act") was the nation's first state law to integrate carbon emissions considerations into regional and local land use planning. The law requires the state's metropolitan planning organizations (MPOs) – the key regional planning bodies – to adopt plans to meet 2020 and 2035 targets for reductions in carbon emissions from passenger vehicles. Passenger vehicles are the largest single source of greenhouse gas (GHG) emissions in California at 25% of the statewide inventory, as shown in Figure 1.

Figure 1. California GHG Emissions by sector in 2013[10]



Today, CARB is also in the process of considering whether or not to urge modified emissions reduction targets to be achieved through revised Sustainable Communities Strategies (SCSs). This study evaluates the trajectory implied under the current SCSs, and the additional benefits that would be captured through stronger steps.

3. BACKGROUND

Though there are substantial benefits and ample opportunities associated with intensified efforts, it should be recognized that California has already been making progress in promoting smarter land use.

Assembly Bill 32 (AB 32), California's Global Warming Solutions Act, was the first economy-wide emissions reduction mandate put in place in the Western Hemisphere. Signed into law in 2006, it established a target for the state to reduce GHG emissions to 1990 levels by 2020. From the outset, better land use planning at the local and regional level has been a part of the package of actions planned to achieve this goal, as seen in the initial draft policy blueprint (the AB 32 "Scoping Plan") released in June of 2008 (CARB 2008, p. 11). By the time the final Scoping Plan had been adopted in 2009, a process to set regional smart growth targets had been signed into law as SB 375.

The SB 375 targets link to land use planning and transportation funding via the MPOs' Regional Transportation Plans (RTPs)/SCSs. The MPOs are uniquely positioned to holistically plan for and address land use, transportation, and housing challenges that are otherwise not effectively addressed in city-by-city planning processes. The SCS process, which includes the development and analysis of alternative scenarios, provides the essential context for state, regional, and local planning decisions. Linking funding allocation to the SCS and giving MPOs more effective and robust implementation tools is critical

[10] 2013 are most recent data available (CARB 2015).

to meeting the state's energy and climate targets, as well as increasingly urgent water, public health, equity, and fiscal challenges.

In 2013, California adopted SB 743, which is leading to changes in the way that new developments are evaluated under the California Environmental Quality Act (CEQA). SB 743 addresses existing regulatory barriers to transit-oriented development, in part by seeking to replace roadway level of service (LOS) standards, which emphasize traffic impacts, with VMT-based standards that aim to reduce environmental impacts by offering more mobility options. SB 743 will encourage location-efficient projects consistent with regional SCS planning, local general and specific plans, and transit investment.

California's cap-and-trade program, launched in 2012 with AB 32 authority, provides a nearly economy-wide carbon price. Auctioning the tradeable permits needed for compliance brings California billions of dollars in annual proceeds to support a low-carbon transition. Cap-and-trade revenues can play a strong role in promoting more efficient growth patterns, particularly if funds are allocated to support infrastructure and projects that are consistent with SB 375 target attainment. Significant funding from the state's cap-and-trade program is already being allocated towards affordable housing and transit projects that support more focused land use development. Additional targeted funding linked to regional and local planning is called for to achieve these more optimal land use patterns.

4. METHODOLOGY

The analysis uses Calthorpe Analytics' RapidFire model to develop and analyze four future land use scenarios. Energy + Environmental Economics' (E3's) recent modeling of GHG reduction pathways provides inputs for energy use and emissions levels under different technology scenarios. This approach allows for a rich analysis of many policy initiatives and offers answers to questions raised by SB 375 and the state's economy-wide climate policy.

This methodological exposition starts, in Section 4.1, with the development of four different future land use scenarios and their associated building and travel characteristics. These are central to the methodology, as different land use patterns drive different travel behavior and building characteristics, and these in turn drive energy, emissions, and other calculated impacts.

Section 4.2 describes the technical assumptions about vehicles, transportation fuels, energy supply, and building energy efficiency as developed by E3 for their California PATHWAYS project (E3 2015). E3 developed a range of scenarios to represent different future technology and emissions paths to 2030 and beyond. With this analysis, we incorporated a subset of three scenarios that span the range of achievement potential – the *Reference*, *Straight Line*, and *Early Deployment* cases.

Section 4.3 gives an overview of Calthorpe Analytics RapidFire model, which is a programmatic sketch-planning tool designed to project the impacts of land patterns on a range of interconnected metrics including passenger vehicle travel, building energy use, water use, land consumption, public health, and local fiscal impacts. The RapidFire model analyzes GHG emissions from the passenger transportation and residential and commercial building sectors, which together are responsible for roughly half of California's emissions.

4.1 LAND USE SCENARIOS

The land use scenarios analyzed for this study were developed to reflect a range of potential development futures that could occur with varying levels of strategic land use planning and implementation. The statewide scenarios each accommodate growth projections to 2030 and beyond and serve to bracket the potential impacts of land use, policy, and technological progress in the transportation and energy sectors across a suite of performance metrics. All scenarios assume the same growth projections for population, households, and jobs into the future — around 6.5 million additional people, 1.8 million households, and 3.8 million new jobs by 2030[11] — but vary in the patterns and relationship to transportation infrastructure in which that growth is projected to occur.

This study examines the impact of four land use scenarios:

1. **Past Trends**: projects forward the relatively expansive, auto-oriented land use patterns of decades past.
2. **Current Plans**: represents plans developed for the first round of SB 375-mandated SCSs by the state's major MPO regions. This scenario reflects our best assessment of the most likely future trajectory for land use given current policy.
3. **More Compact**: features more focused growth planned in close coordination with transportation investments, aimed towards meeting increased demand for more diverse community and housing types as projected by A.C. Nelson's comprehensive California housing market demand study sponsored by the Urban Land Institute (Nelson 2011).
4. **Infill Focus**: maximizes infill and redevelopment potential and responds to changing housing demand as projected by Nelson (2011).

Each of the four scenarios is defined by the allocation of population and job growth to three "Land Development Categories" (LDCs). Together, the LDCs encompass the spectrum of development types and conditions seen across California. The scenarios are described in more detail following an overview of the core characteristics of the LDCs.

4.1.1 Characteristics of Land Development Categories

The LDCs are defined by different land patterns, street networks, and building types, and the allocation of people and jobs across these. The amount of residential and commercial building area varies according to the development patterns of the LDCs. Household travel behavior (i.e. driving, walking, biking, and transit use) also varies significantly among the LDCs.

The three LDCs – Urban, Compact, and Standard — represent distinct forms of land use, ranging from dense and walkable mixed-use urban areas well served by transit, to lower-intensity, less walkable

[11] These are numbers compared to 2012 levels, reflecting the demographic assumptions in the E3 CA PATHWAYS study.

places where land uses are segregated and most trips are made via automobile. These different patterns result in significant differences in transportation, environmental, and fiscal performance.

The attributes of the three LDCs used in this analysis are as follows:

- **Urban**. This is the most compact and mixed category, which in most cases would be found within and directly adjacent to moderate- and high-density urban centers. Nearly all new development that falls into the Urban LDC would be infill or redevelopment. The majority of housing in Urban areas is multifamily and attached single-family (townhome), with some smaller lot single-family homes. Commercial development occurs primarily in mid- to high-rise buildings.

  Successful Urban growth requires the support of high levels of regional and local transit service (likely on dedicated rights-of-way and including multiple modes such as rail, bus, and ferry), well-connected street networks, and mixed-use development. The mix and intensity of uses result in a highly walkable environment that leads to a relatively low dependence on the automobile for many trips. The per-capita VMT of those living in Urban environments are far lower than average and generally range, in California, from 1,500 to 4,500 VMT per year. Households in Urban areas also consume, on average, less water and energy than those in other LDCs due to their more compact profiles.

- **Compact**. Development in this category is less dense than the Urban LDC, but is nonetheless highly walkable and contains a mix of retail, commercial, residential, and civic uses. The historic cores of many of California's mid- and smaller-size cities fall into the Compact category. As new growth, the Compact form is most likely to occur on the urban edge or as larger-scale (ground-up) redevelopment within urbanized areas. Housing may be developed as part of mixed-use developments or plans, or with access to existing commercial areas. The same is true for new commercial development, which can take the form of low- to mid-rise buildings.

  It is assumed that Compact growth is well served by regional and local transit service, but may not be as well served as Urban areas, and is less likely to occur around major multimodal hubs. Streets are well connected and walkable, and destinations such as schools, shopping, and entertainment areas can typically be reached via a walk, bike, transit, or short auto trip. The per-capita VMT of those living in Compact environments tends to be lower than average and generally ranges from 4,500 to 7,500 VMT per year in California. While the mix of housing types in Compact areas is generally not as resource-efficient as that in Urban areas, households tend to consume less energy and water on average than those in the larger types of the Standard LDC.

- **Standard**. This category represents the majority of separate-use, auto-oriented development that has been predominant in the American suburban landscape over the past five to six decades. Densities tend to be lower than that of the Compact LDC. Land uses are generally not highly mixed or organized in ways that facilitate walking, biking, or transit service. While Standard communities can contain a wide variety of housing types, including attached and multifamily units, medium- and larger-lot single-family homes comprise the majority of this development form. On the commercial side, Standard development typically occurs in the form of big-box retail stores, strip malls, and office parks. For the purposes of this study, rural growth is included as Standard development.[12]

The lower densities and decreased mix of uses in the Standard LDC are not typically well served by regional or local transit service, so most trips are made by car. The built environment tends to be oriented around automobile usage as the primary mode for mobility. Standard communities typically have a low index of street intersections per square mile, many discontinuous streets that channel traffic onto arterials, long blocks, and single-use zoning. Standard areas are often located in and around the periphery of metropolitan regions. The per-capita VMT of those living in Standard environments tends to be higher than average due to auto dependence for most trips, and generally ranges from 8,500 to 14,000 VMT per year in California. The larger single-family housing types that dominate this development form tend to demand more energy and water than the housing types in the Urban or Compact LDCs.

[12] While rural development characteristics are distinct from the suburban development that generally typifies the Standard LDC, rural growth is accounted for in the performance assumptions of the Standard LDC.

Figure 2. Photos illustrating LDC characteristics

Housing Types

The RapidFire model categorizes housing into four types: larger lot single-family detached, smaller lot single-family detached, townhomes, and multifamily homes. Larger lots are defined as those 5,500 square feet and above (representing a minimum gross density of ~5.5 units per acre), while smaller lots fall below that. These housing types are associated with different development densities, fiscal impact assumptions, and profiles for energy and water use. Housing type is not directly associated with household travel behavior.

Greenfield and Refill Development

Growth in housing and jobs takes place in either "greenfield" or "refill" locations, which can significantly impact transportation system use and infrastructure requirements. Greenfield land refers to previously undeveloped land at the urban edge and beyond, including agricultural land, forest land, desert land, and other open space areas. The term "refill," in model terms, refers to both infill development in areas within or bounded by existing urbanized areas, and redevelopment of existing urban sites. Refill can occur on small and large-scale sites, including underused or abandoned greyfields and brownfields – lands previously used for urban, industrial, or other development that are typically located within or adjacent to currently urbanized areas. Refill locations are generally more efficient from a transportation standpoint due to better regional accessibility, and fiscally efficient in terms of local infrastructure development, operations, and maintenance costs.

All Urban development occurs as refill, Compact development occurs mostly as refill, and Standard development occurs mostly on greenfield land. The proportion of new population and job growth occurring as greenfield and refill development in each scenario is set to reflect either past trends or the direction of plans and policies going forward.

Performance Characteristics

The variations in housing mix, transit level of service, walkability, location efficiency, mix of uses, and other variables among the LDCs collectively affect travel, energy and water use, land consumption, and infrastructure impacts, as quantified through the application of factors linked either to the component housing types (e.g., average annual electricity use for multifamily homes) or the LDCs themselves (e.g., per-capita VMT for residents of Compact areas). The typical baseline performance characteristics of the LDCs are summarized in Table 1.

Table 1. Typical annual per-capita performance characteristics, by Land Development Category (2012)

	Urban	Compact	Standard
Vehicle miles traveled (VMT)	4,300 miles	6,000 miles	10,000 miles
Residential energy use	17 million Btu	19 million Btu	26 million Btu
Residential water use	25,000 gallons	29,000 gallons	44,000 gallons
Carbon emissions from passenger VMT and residential energy use*	3.1 metric tons	4.0 metric tons	6.2 metric tons
Residential energy costs (transportation and utilities) **	$3,000	$4,000	$6,500

** Transportation emissions include those associated with fuel combustion or the generation of electricity or hydrogen as a fuel, but not emissions from petroleum refining, oil and gas extraction, or other upstream industrial activities.*

***Transportation costs include those related to private passenger motor vehicle travel, and are expressed in 2015 dollars.*

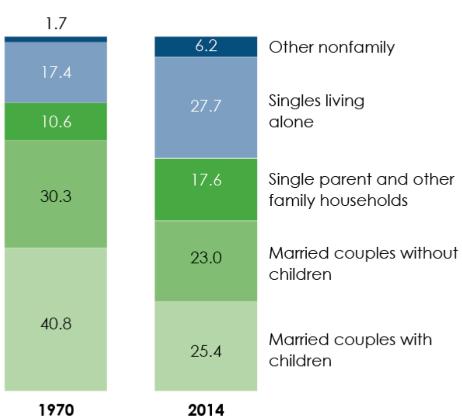
Performance in future years is impacted by the influence of land use patterns over time (in the case of passenger vehicle travel), as well as assumptions about vehicles, fuels, and building energy efficiency. The basis for variations in transportation and building energy performance among LDCs are explained in the Methodology section of this report.

Changing Housing Demand

The related trends of changing household demographics and growing preference for compact housing types have informed the housing unit mix composition of the scenarios. The proportion of housing types in the More Compact and Infill Focus land use options is likely to be achievable and desirable – meaning in line with consumer preference – as indicated by real estate market analysis that indicates that demand is moving away from larger single-family detached homes toward smaller detached or attached housing units. Affordability, accessibility, and demographics are key factors behind this change. Nationally, analysts predict that apartment and townhome living near transit will drive much housing demand going forward. Lifestyle preferences also play a role: a survey of Atlanta households found that 40% of those living in single-family detached neighborhoods would trade large lots for smaller ones with more community-friendly amenities, including sidewalks, narrower streets, shops and services, and parks (Nelson 2009).

Changes in housing preference are also grounded in demographic changes. Married couples with children, the primary market for single-family detached homes, now account for only 23% of all households nationwide, a proportion that continues to shrink each year (Levine, Frank, & Chapman 2004). By contrast, the proportion of singles, single parents, empty nesters, and seniors – who generally prefer more compact single-family and multifamily housing types – has grown steadily (Nelson 2003). These demographic shifts are shown in Figure 3, which reveals the changing composition of American households.

Figure 3. Changing household demographics, 1970 to 2014



Source: U.S. Census Bureau, 2014

Further analysis indicates an ongoing disconnect between housing type supply and demand; despite demographic trends and expressed preferences, single-family homes accounted for the majority of new construction over the last decade. A 2011 Urban Land Institute study of the housing market in California found that, by 2035, “the four largest MPOs may have nearly three million more units on conventional lots (those larger than one-eighth acre) than the market may demand” (Nelson 2011). By contrast, demand for attached and small-lot single family homes, and those in transit-station areas, is underserved and thus very high.

4.1.2 Scenario Development

Scenarios are built by allocating projected population and job growth to the three LDCs. Depending on the scenario, the distribution of growth to LDCs can be informed by analysis of past development trends, local and regional plans and policies, and other long-range planning efforts. Thus scenarios can reflect trend development, alternative futures, or other policy considerations by varying LDC proportions accordingly. These variations, and their interaction with existing conditions, determine the results under each scenario.

While the RapidFire model is aspatial in terms of the specific location of new growth, it incorporates geographic data and analysis to assess past trends and translate future plans. In the case of past trends, growth by LDC is estimated using data indicating land use change and housing growth by type over time. Regional plans or scenarios, which in turn incorporate local planning input, are "translated" into growth distributions by LDC through analysis of their residential and employment allocations and land use designations.[13] To construct statewide scenarios, the translated regional scenarios – including current RTP/SCS plans and scenario alternatives developed by the regions – are blended together in proportion to their projected share of growth.

4.1.3 Four Possible Land Use Futures for California

Having described the characteristics of LDCs and the process for specifying these, next we describe in specific terms the four future land use scenarios at the core of this study.

Past Trends

This scenario posits a future in which development occurs much as it has over the past several decades, with most growth occurring in Standard suburban patterns oriented towards private auto use, facilitated by ongoing roadway expansion. Although California has already begun to steer away from this paradigm through legislation guided by goals for environmental sustainability, and impelled by the housing finance crisis of 2008 and subsequent recession, it is meaningful to recognize the consequences of continued sprawl. While California's MPOs and other regional agencies are tasked with comprehensive long-range planning to direct transportation investments, land use authority ultimately resides at the local level. Cities, counties, and regions throughout the state are working towards better coordination in planning, though this is an ongoing process and not a guaranteed outcome. Without sufficient resources to support local planning consistent with target-oriented regional plans, Standard development patterns are likely to prevail.

The Past Trends scenario is comprised of 5% Urban, 25% Compact, and 70% Standard growth. Housing growth to 2030 is 15% multifamily, 15% townhome, 16% smaller lot, and 54% larger lot. On the whole, approximately 30% of growth is assumed to occur as refill development. The resulting total housing distribution in 2030 is 29% multifamily, 8% townhome, 18% smaller lot, and 45% larger lot.

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[13] Calthorpe Analytics worked with the Southern California Association of Governments (SCAG) and the San Diego Association of Governments (SANDAG) to apply the map-based UrbanFootprint model in regional scenario development and analysis. This work involved the translation of plans and definition of scenario alternatives into UrbanFootprint place types, which in turn nest into the LDCs of the RapidFire model framework.

The Past Trends scenario is conceptually akin to the Baseline case in the E3 California PATHWAYS modeling work, while the Current Plans scenario, profiled next, is analogous to the way that the E3 Reference case treats energy technology.

Current Plans

The Current Plans scenario represents a compilation or "stitch" of the first-round RTPs/SCSs produced by the state's major MPOs in accordance with SB 375. Representing about 93% of the state's population in total, the state's major MPO regions include (in descending order of population): Southern California, the Bay Area, the eight counties of the San Joaquin Valley, San Diego, and the Sacramento area. The regions' first SCSs were developed following the process that, in coordination with CARB, resulted in targets for per-capita GHG reductions from 2005 for the years 2020 and 2035.

The statewide LDC and housing mix of the Current Plans scenario reflects a population-weighted distribution of the fiscally constrained RTP/SCS plans by each of the regions, or counties in the case of the San Joaquin Valley, to horizon years as far out as 2050. SCS plans for the Southern California, San Diego, Sacramento, and San Joaquin Valley regions were translated as part of Calthorpe Analytics' current and past work with the MPOs (using the GIS-based UrbanFootprint land use planning model as well as RapidFire), while the Bay Area SCS (*Plan Bay Area*) was interpreted on the basis of growth projected in transit-proximate Priority Development Areas (PDAs) and the projected share of multifamily households by 2035.

While the regional SCS plans vary in accordance with geographic, demographic, economic, and other conditions, from a land use planning perspective they share two core precepts: a) focusing housing and job growth in transit-proximate, location-efficient areas; and b) diversifying housing growth to include more compact options in line with projected demand, including multifamily homes, townhomes, and smaller-lot single family homes. The depth of potential per-capita VMT (and subsequently, GHG emissions) reductions, the primary criteria of SCS performance measurement, is largely dependent on the extent to which these goals can be achieved.

The housing mix of the Current Plans scenario reduces conventional larger-lot development, instead aligning more closely with changing demographics and housing preferences for smaller lot and attached housing types, and transit-accessible and walkable locations. Close to 60% of new growth is accommodated by attached housing types, including multifamily units and townhomes. The Current Plans scenario is comprised of 15% Urban, 35% Compact, and 50% Standard growth. Housing growth to 2030 is 44% multifamily, 15% townhome, 24% smaller lot, and 17% larger lot. Approximately 45% of growth occurs as refill development in regionally designated priority development areas (PDAs) and other infill locations. The resulting total housing distribution in 2030 is 32% multifamily, 8% townhome, 20% smaller lot, and 40% larger lot.

By our assessment, the Current Plans scenario reflects a plausible trajectory for future development, given current policy, planning activities, and development conditions.

More Compact

The More Compact scenario features an increasing proportion of Urban and Compact development. Slightly more growth is allocated to Urban areas as compared to the Current Plans scenario, while the majority of growth overall occurs as Compact development. From a regional planning perspective, this scenario entails a stronger prioritization of development in and around existing cities and towns and along major transportation corridors, and significant new transit investments to support denser development and improve regional accessibility. Standard development is significantly curtailed in favor of Compact development that makes better use of existing infill opportunities. The composition of this scenario reflects the direction of the most progressive, non-fiscally constrained scenarios being modeled for next-round RTP/SCS planning, though on a shorter timeline to 2030. Realizing the development pattern of this scenario would require strong implementation support for coordinated regional and local planning.

The housing mix of this scenario addresses the current and projected undersupply of homes in compact, walkable, transit-accessible neighborhoods. While some larger-lot development still occurs, townhomes, multifamily homes, and smaller-lot single family homes contribute to a diversity of options, aligning with housing demand as projected by the Urban Land Institute's study of demographic and economic trends in California's major MPO regions (Nelson 2011). While that study finds that the existing supply of larger lot single-family homes well exceeds demand into the foreseeable future, the More Compact scenario allows for some continued new larger-lot development that is still likely to occur in some areas around the state.

This scenario envisions 20% Urban, 60% Compact, and 20% Standard growth. Housing growth to 2030 is 36% multifamily, 27% townhome, 27% smaller lot, and 10% larger lot. Over 60% of growth is assumed to occur as refill development. The resulting total housing distribution in 2030 is 31% multifamily, 10% townhome, 20% smaller lot, and 39% larger lot.

Infill Focus

The Infill Focus scenario was developed to test the impacts of accommodating the vast majority of growth through infill and redevelopment. In this scenario, as under the More Compact scenario, most new growth occurs as Compact development. Urban areas absorb a significant proportion of growth, while Standard growth is minimal. The scenario stops short of allocating all new development to refill locations since some greenfield development is bound to occur both inside and outside the major MPO regions. The high levels of refill envisioned by this scenario are guided by projections of available capacity, particularly in the form of underutilized nonresidential land.[14] Maximizing usage of that

[14] According to Nelson's housing demand study, which also projected the replacement and growth of nonresidential space to 2035, "Recycling the land on which nonresidential spaces already exist will probably be sufficient to accommodate a substantial share, if not all, of the additions to the nonresidential inventory," and that, "between 2010 and 2035, net new demand for multifamily residential development could conceivably be included in the redevelopment of existing nonresidential parcels and accommodate replacement of existing space" (Nelson 2011).

capacity would entail significant intervention and strategic actions to address regulatory and market challenges to infill and redevelopment.[15]

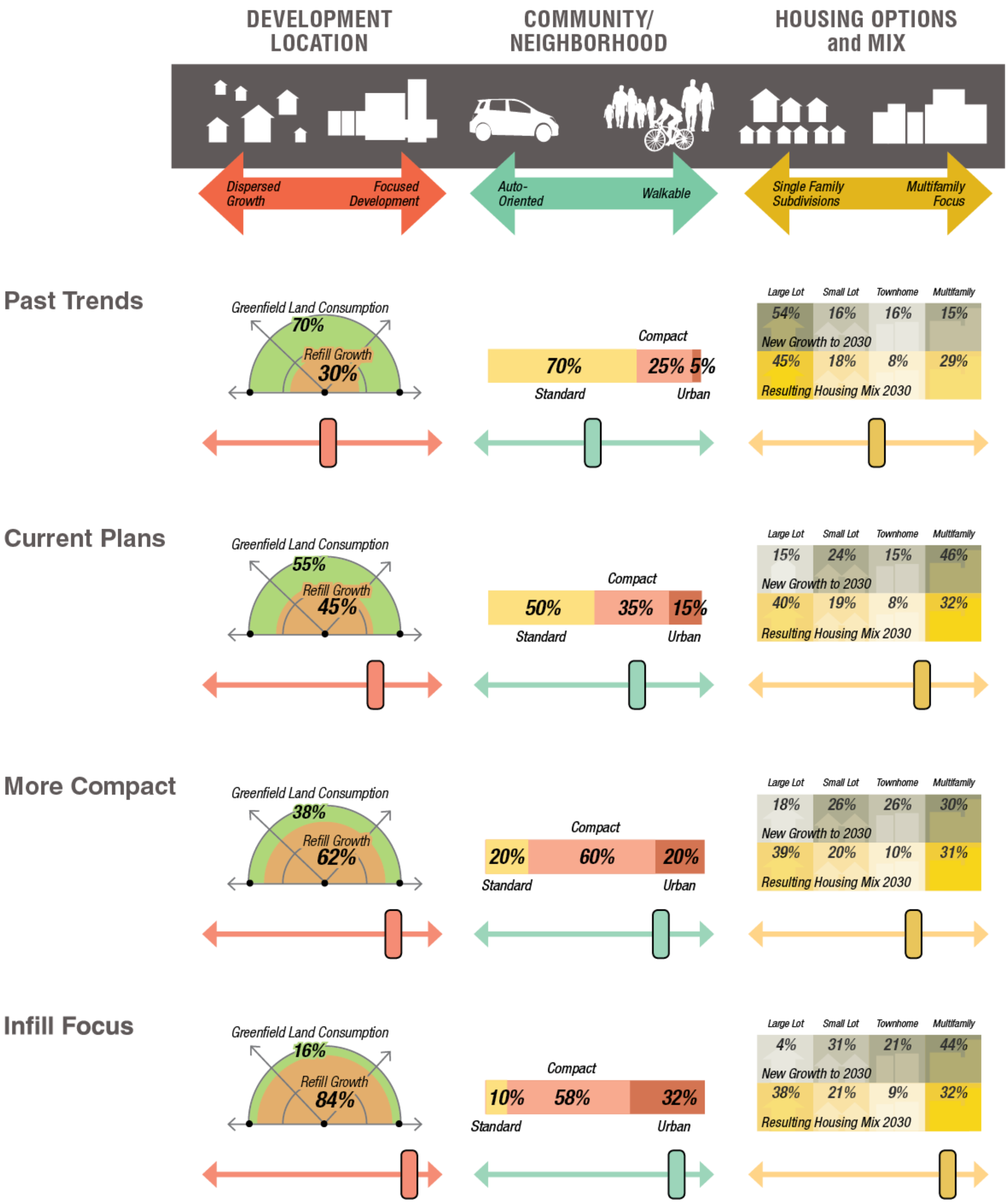
The housing mix of the Infill Focus scenario is similar to that of the More Compact scenario in aligning with housing demand for a range of options in compact, walkable, and transit-accessible areas. With the increased proportion of Urban development, the Infill Focus scenario includes a greater share of multifamily homes as compared to townhomes, and a lower combined share of single-family detached homes.

The Infill Focus scenario is comprised of 30% Urban, 60% Compact, and 10% Standard residential growth. Housing growth to 2030 is 44% multifamily, 21% townhome, 33% smaller lot, and 2% larger lot. Approximately 85% of growth is assumed to occur as refill development. The resulting total housing distribution in 2030 is 32% multifamily, 9% townhome, 21% smaller lot, and 38% larger lot.

The scenarios are summarized in Figure 4. *Development Location* indicates the allocation of new population and job growth to either greenfield or refill locations. *Community/Neighborhood* indicates the proportions of growth allocated to each of the LDCs. Lastly, *Housing Options and Mix* summarizes the proportions of new housing growth by building type, and the resulting overall housing mix in 2030.

[15] In recognition of the importance of infill development in achieving GHG reduction targets, in 2014 the California Strategic Growth Council commissioned a report to identify infill development constraints and strategies. For more, see: Economic and Planning Systems, Inc., 2014.

Figure 4. Land use scenarios summary



4.2 E3 TECHNOLOGY SCENARIOS

In large part our study was undertaken to inform the land use component of the discussions regarding how to achieve the new 2030 goals that the state has articulated. As such, we emulated the assumptions and outputs used in the E3 California PATHWAYS study to the maximum extent possible.[16] This approach was informed by CARB's 2009 collaborative modeling exercise, which illustrated the value of being explicitly transparent about assumptions.[17]

To explore the role that land use would play under a broad range of conditions, the scenario outputs used in this study span a broad range of possible technology futures as represented by three of the E3 scenarios: the Reference, Straight Line, and Early Deployment cases. E3's own inputs were used where possible, while other required inputs for the RapidFire model were derived from the E3 scenario outputs. The Reference case, which limits future improvements to the extent of current policy, is the least ambitious scenario we employ. Early Deployment, the most aggressive case, reduces statewide carbon emissions to 38% below the 1990 level by 2030. As an intermediate case, we also apply E3's Straight Line case, which follows a straight-line trajectory to reduce emissions to 80% below by 2050 (meeting AB 32's long-term emissions target), and achieves a reduction in statewide carbon emissions of 33% below 1990 by 2030.

The E3 Reference case reflects the 33% Renewables Portfolio Standard currently in law while the Straight Line and Early Deployment scenarios achieve 50% and 60% renewable electricity by 2030, respectively. The Early Deployment case would also require large-scale vehicle electrification. In addition to core energy and emissions variables, every effort was used to follow other assumptions used by E3, including the population growth rate to 2050 and energy prices for household costs.

E3's electricity and vehicle results were straightforward to apply. The E3 results offer year-by-year electricity carbon intensity measures for each scenario. The same can be said for the passenger vehicle stock mix for each year, which includes a detailed characterization of vehicles and their fuel efficiencies. The energy intensity of gasoline, diesel, LPG and other fuels are also given for every year, though not the total amount of fuels consumed in volumetric or mass terms, nor the carbon intensity by volume consumed. To manage this, we imputed the per-gallon emissions for gasoline and diesel fuels and assumed values from other research literature for hydrogen fuels and electricity. The steps taken to incorporate the E3 transportation assumptions, as well as those for building sector energy, are described further in Appendix A.

To allow for an apples-to-apples comparison between the E3 emissions results and those of the RapidFire scenarios, the E3 scenarios – with direct VMT inputs representing their general land use component – were run in RapidFire. Thus we can examine the incremental difference in emissions

[16] For a detailed discussion of the E3 study, see their documentation (E3 2015a).

[17] CARB launched the 2009 collaborative modeling exercise in response to the different results regarding the economic impacts of the original AB 32 Scoping Plan that various modeling groups had generated. To try to make more sense of the results, another round of modeling was conducted with greater convergence around common assumptions. CARB staff organized a public meeting to update the Board on the outcome of this process. The agenda can be found here.

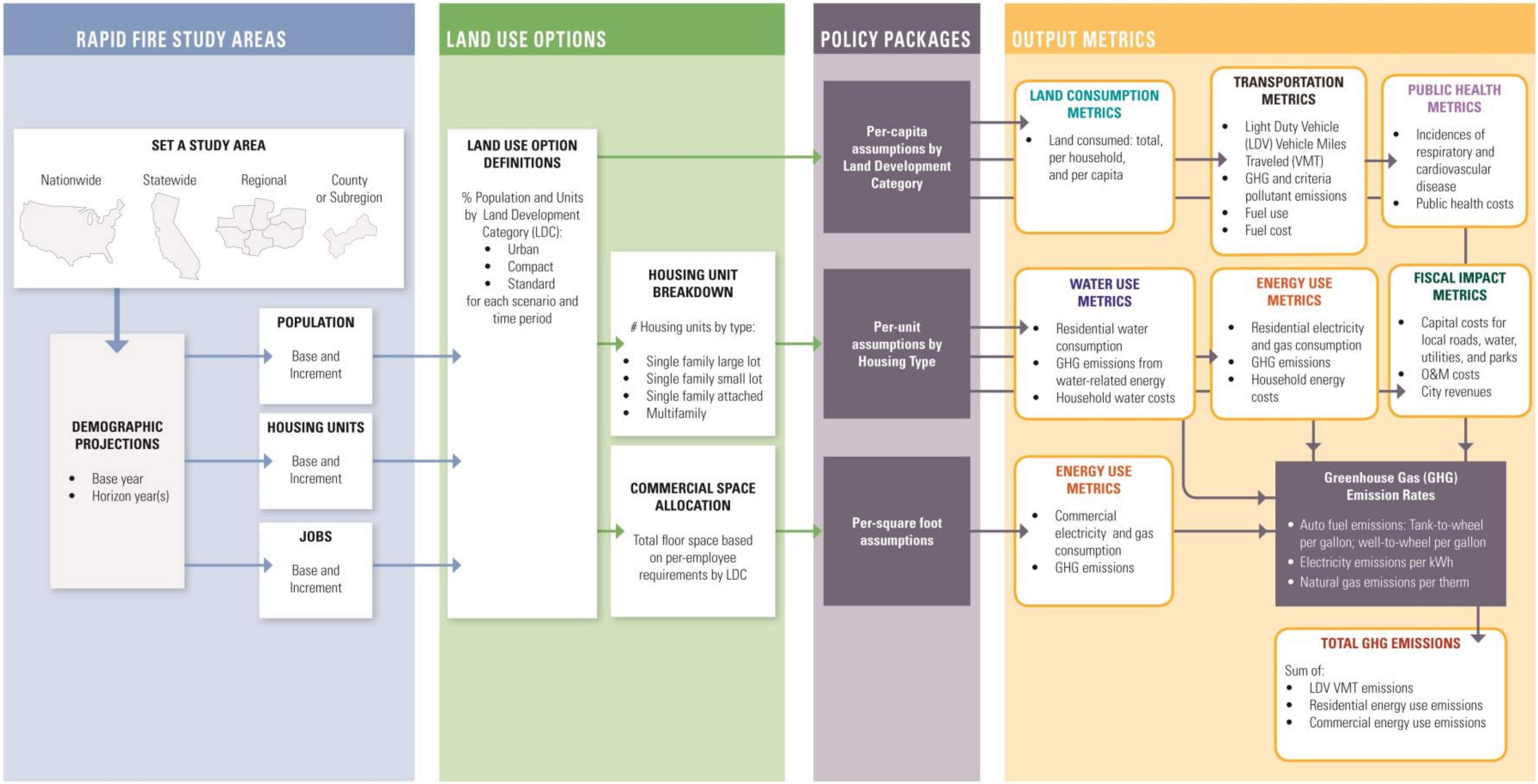
attributable to the impacts of this study's land use scenarios on passenger vehicle travel and building energy use.

4.3 THE RAPIDFIRE MODEL

RapidFire is a spreadsheet-based tool that constitutes a single framework into which data and research-based assumptions about the future are loaded to test the impacts of varying land use patterns and policies across a range of critical metrics. RapidFire emerged out of the need for a comprehensive modeling tool that could quickly inform state, regional, and local agencies and policy makers in evaluating land use, energy, water, transport, and infrastructure investment policies. Since 2010, it has been deployed across California and the United States, and adapted for use in Mexico City. RapidFire measures the impact of land use scenarios for a range of metrics – VMT, energy use, and related GHG emissions pursuant to SB 375 and AB 32 targets, as well as land consumption, water use, public health impacts from transportation emissions, and local fiscal impacts. The following sections describe how the output metrics are calculated, with an emphasis on the energy and air emissions.[18] Figure 5 offers a broad overview of the model flow, from scenario options and policy-based technical inputs to output metrics.

[18] Further information about the RapidFire model is available at calthorpeanalytics.com.

Figure 5. RapidFire model flow



4.3.1 Transportation Sector Impacts: Passenger Vehicle Miles Traveled

RapidFire projects passenger vehicle travel, also referred to as household travel (as opposed to travel for commercial or goods movement purposes), as a function of land use patterns. As a sketch model, it was not designed to replace more complex regional travel models or map-based models. Rather, RapidFire incorporates research from leading experts and data on the relationship between land use, urban form, and VMT to project the changes that can occur as a result of long-term shifts in land use and transportation patterns.

RapidFire calculates passenger travel by applying per-capita VMT assumptions to base-year population and future growth by land development category. Baseline rates are calibrated to year-2012 VMT as estimated by the CARB Emissions Factors (EMFAC) 2014 model,[19] while future-year rates vary according to characteristics of the Urban, Compact, and Standard LDCs. Moreover, shifts in travel are projected to occur over time as regions grow to become either more compact or more dispersed, as determined by the relative proportion of growth by LDC in a scenario.

The "D" Variables

The relationships between travel behavior and urban form as represented by the RapidFire assumptions are supported by extensive research being used to inform regional travel demand model development and application in California and across the U.S. (Ewing, Bartholomew, Winkelman, Walters, & Chen 2008; Lee and Cervero 2007; Littman 2007; Ewing and Cervero 2001; Holtzclaw 2002; Holtzclaw, Burer, & Goldstein 2004). In the world of travel demand modeling, urban development patterns have come to be characterized by a series of "D" variables, including density, diversity, design, destination, and distance to transit:[20]

- *Density* refers to the number of persons, jobs, or homes in a community or designated area.
- *Diversity* refers to the mix of land uses in a community or area and the balance of jobs, housing, shopping, schools, and other daily needs and services.
- *Design* refers to the interconnectedness of the street network in a community, and can be measured in terms of intersection density, sidewalk completeness, block size, and other factors that combine to determine how walkable the community is and how far one destination is from another – whether travel is by car, foot, bike, or transit.
- *Destination* refers to a community's accessibility in the larger city or region and how connected it is to other centers of activity.
- *Distance to transit* refers to the level and type of transit service in a community and is measured as the distance from home or work to the nearest rail or bus station or stop.

Table 2 summarizes the general characteristics of the RapidFire land development categories in terms of the "Ds". The model assumes that requisite transportation investments go hand in hand with growth

[19] Passenger vehicle VMT is counted for four vehicle classes: light-duty autos (LDA), light-duty trucks (LDT1, LDT2), and medium-duty vehicles (MDV).

[20] The "D" variables have grown to eight separate variables, including demographics, demand management, and development scale.

patterns, such that scenarios with a greater focus on Compact and Urban development would see increased transit, bicycle, pedestrian, streetscape, and livability investments. Conversely, scenarios consisting of predominantly Standard growth would see large budget outlays to build out sprawling highway and road expansion, and less investment in existing urban areas.[21]

Table 2. Land Development Category (LDC) characteristics

	DENSITY	**DIVERSITY**	**DESIGN**	**DESTINATION**	**DISTANCE TO TRANSIT**	**VMT**
LDC	*Residential & Commercial Density*	*Mix of Land Uses*	*Pedestrian-Orientation & Walkability*	*Accessibility & Connections to Activity Centers*	*Level of Type Transit Service*	*VMT per Household*
Urban			- High -			Low
Compact			- Medium -			Medium
Standard			- Low -			High

Additionally, new growth impacts the VMT of residents of currently existing developed areas (the "base" population in model terminology). New Standard growth at the periphery of cities and regions increases average VMT in existing areas, while refill decreases it.[22] For example, if one is living in an area that, in ten years, sees increased transit service and/or new retail development in close proximity to their home or workplace, it is likely that they will drive less (and walk, bike, or take transit more) in the future because destinations and services become more accessible. Conversely, if refill development is limited while new growth and destinations expand outwards, one is likely to drive the same amount as today, if not more. The positive or negative effect of new development on the VMT of those living in existing areas is determined by the relative proportions of Urban and Compact refill vs. Standard growth in a scenario. The degree and directionality of this effect is also determined by the proportions of Urban and Compact refill vs. Standard growth in a scenario. The methodology for projecting the impact of new growth on the travel behavior of residents in already built-out areas has been peer-reviewed and is supported by "D" variable research, analysis of empirical data, and studies into the relative impacts of regional location and development context on VMT (Ewing & Cervero 2001; Fehr & Peers 2006).

The baseline and future per-capita VMT ranges for each LDC are summarized in Table 3. The initial variations in VMT by LDC, expressed in terms relative to the statewide baseline average, are rooted in empirical data from representative cities and communities throughout California.[23] For this study, they have undergone further calibration using more recent modeled household average VMT estimates at the block group level, as presented in the Housing + Transportation (H+T®) Affordability Index by the

[21] While the model calculates local infrastructure costs on a net basis, regional transportation infrastructure investments, whether for roadways, transit, or active transportation, are not estimated.

[22] The impact of new growth on VMT associated with existing development as posited in RapidFire has been peer-reviewed by Robert Cervero (UC Berkeley) and Jerry Walters (Fehr & Peers) and assessed to be consistent with the researched effects of regional location ("destination") and other "D" variables on VMT.

[23] TAZ-level data from Holtzclaw, Clear, Dittmar, Goldstein, & Haas (2002)

Center for Neighborhood Technology (CNT)[24], to assess VMT ranges in representative locations, as well as the distribution of per-capita VMT rates statewide. VMT variations for new growth population into the future are estimated with respect to scenario context (the relative proportions of Urban and Compact refill, or Standard growth). The low end of the ranges reflects average VMT rates in the most focused 2030 land use scenario, while the high end of the ranges reflects average VMT in the most dispersed scenario.

Table 3. Annual per-capita VMT by LDC, Baseline and 2030

	Annual per-capita VMT
Baseline average, 2012	7,200 mi
New growth in Urban LDC, 2030	2,200 to 4,300 mi
New growth in Compact LDC, 2030	4,300 to 6,000 mi
New growth in Standard LDC, 2030	8,100 to 11,000 mi

VMT Calibration

VMT is calibrated to the year 2012, selected as the "baseline year" in the model to incorporate empirical (rather than projected) data across the modeled sectors. To establish the baseline average per-capita VMT, we use data from CARB's most recent EMFAC 2014 model,[25] calculating the average by annualizing the daily statewide VMT totals for the LDA, LDT1, LDT2, and MDV passenger vehicle classes (assuming a factor of 347, as advised by CARB), and dividing by population as estimated by the California Department of Finance.

In using the latest EMFAC estimates as a starting point, the VMT results take into account declines in VMT evidenced since 2005 that represent a significant shift in travel behavior. By projecting forward from this best-available baseline data, this analysis captures recent dynamics, and assumes that shifts that have already occurred will be intrinsic to travel behavior into the future.

It should be noted that the scenario results capture the effect of land use, urban form, and transportation infrastructure on VMT as has been evidenced until now. The results do not project macroeconomic or specific demographic trends that will affect travel behavior into the future, except to the extent these are embedded in the projections taken as inputs from the E3 study. Nor do they account for emerging transportation trends, for example, technology-enabled ride-hailing, ridesharing, autonomous vehicle systems, or electric bike use; the relationship between these new modes and land use patterns, and their resulting impacts on travel behavior, will require study as they take hold.

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[24] The H+T® Affordability Index is an online tool that presents average housing and transportation costs at the neighborhood level to provide a comprehensive view of affordability through the lens of location efficiency (CNT 2015).

[25] The EMFAC model results can be accessed at a dedicated page on the CARB website.

It should also be noted that VMT results are not sensitive to fleet characteristics (e.g., the share of alternative-fuel vehicles); VMT is distributed among the vehicle types in direct proportion to their share of the vehicle fleet.

GHG Emissions, Pollutant Emissions, and Costs

GHG emissions, air pollutant emissions, and costs associated with passenger vehicle travel are estimated by applying technical assumptions (for this study, the E3-informed assumptions) to VMT results. GHG emissions are determined by VMT, vehicle fleet mix and fuel economy, and the carbon intensity of the energy sources used to power the vehicles.

Air pollutant emissions are estimated on a per-mile basis as calculated from EMFAC 2014 data for specific future years and according to the vehicle types in the different E3 vehicle fleet projections. Statewide totals will not be indicative of localized impacts. Auto costs include those to power vehicles (including liquid fuels and electricity), as well as costs for ownership and maintenance. Energy costs are estimated per gallon of liquid fuel and kilowatt-hour of electricity, while ownership and maintenance is estimated using a flat cost per mile (refer to Appendix B for assumptions).

Public Health Incidences and Costs

Auto-related air pollution results in a spectrum of health impacts, including incidences of chronic bronchitis; acute myocardial infarction; respiratory and cardiovascular hospitalizations; respiratory-related ER visits; acute bronchitis; asthma exacerbation; acute, lower, and upper respiratory symptoms; work loss days; and premature mortality. Health incidences, and their related costs, are reduced along with miles driven. Comparative savings among scenarios (rather than absolute totals) in health incidences and costs to 2030 are calculated according to a recently completed study from the Environmental Defense Fund, American Lung Association, and Tetra Tech (2014) in California for use in regional and statewide studies. Incidence and valuation rates are applied to tons of pollutant emissions (NO_x, SO_x, CO, VOC, and $PM_{2.5}$).

4.3.2 Building Sector Impacts: Building Types and Floor Area

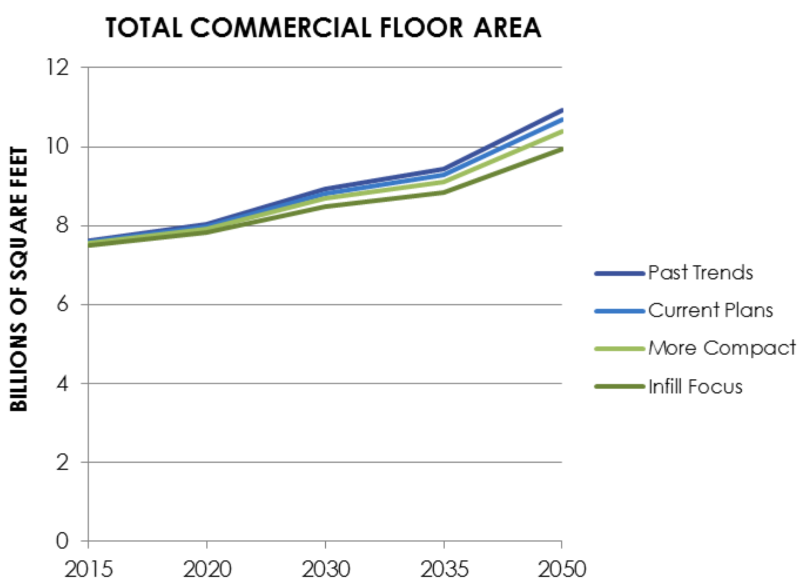
Building energy use and its associated GHG emissions and costs vary according to land use, as well as technical assumptions about energy efficiency and resource mix. Land use can be foundational to reducing energy use since more compact residential units and commercial building types generally require less energy to heat and cool than more spacious ones. The model accounts for variations in energy use as relates to the building program associated with each land use scenario, and assumptions about energy efficiency improvements over time.

RapidFire calculates building energy use for existing and new residential and commercial buildings. Baseline per-unit residential energy use figures are derived from California Energy Commission (CEC) Residential Appliance Saturation Study (RASS) data (KEMA, Inc. 2010), and vary by building type (single-family large lot, single-family small lot, townhome, multifamily). On the commercial side, per-square foot average electricity and natural gas use factors are applied across all commercial building type categories. The baseline commercial energy use figures are calculated using CEC Commercial End-Use

Survey (CEUS) data (Itron, Inc. 2006). The residential and commercial baselines are summarized in Appendix B.

The land use scenarios, which all deal with the same base- and end-year housing and job projections, and the same base-year commercial floor area, depart from the E3 scenarios in their differentiation of housing by type and the projection of new commercial floor area into the future. Both are determined by the land use mix of the scenarios, with the mix of future housing types and average commercial floor area per employee varying for the Urban, Compact, and Standard LDCs. Employment densities differ primarily for retail and office building types in different land use patterns. The housing type mix of the scenarios is summarized in Figure 4, while the commercial floor area by scenario is summarized in Figure 6 (below).

Figure 6. Total commercial floor area by scenario



Into the future, energy use is also dependent on assumptions about building energy efficiency. For existing buildings, the model assumes rates of building retrofits and replacement. For new buildings, the model assumes that new construction will be built to meet increasingly higher efficiency standards (expressed as reductions from the baseline factors). In contrast, the E3 scenarios for building energy efficiency were developed in terms of appliance/technology saturation, with significant shifts from natural gas to electricity use to achieve deeper GHG reductions. To align with the E3 efficiency and electrification assumptions, the end-year effects of their scenarios on electricity and natural gas use per housing unit and commercial square foot, in terms of reductions from 2012 baseline levels, were replicated in RapidFire.

In turn, GHG emissions from building energy are calculated based on assumptions about the resource mix of the electricity and natural gas supply. The per-kWh (kilowatt-hour) and per-therm rates change in each year as progress is made towards targets.

Retail electricity and natural gas prices are also applied on a per-kWh and per-therm basis. The resulting costs are included as a component of household expenditures.

4.3.3 Building Water Use, Emissions, and Costs

RapidFire separately calculates building water use for the existing population of residential buildings and for those of the growth increment. Residential water use is a function of both indoor and outdoor water needs, with outdoor use (landscape irrigation) accounting for the majority of the difference among housing types. Because homes with larger yards require more water to maintain, a household's overall water consumption can correlate generally with lot size. The differences in water use and costs attributable to growth patterns, and their accordant distribution of homes by type, can be significant. The averages are summarized in Appendix B.[26]

As with building energy use, future water use is projected by assuming rates of building retrofits and replacement for existing buildings, and new construction water efficiency standards for growth. While the baseline averages do not expressly account for conservation measures taken in response to the current drought, the efficiency assumptions applied assume efforts in response to a constrained water supply into the future. For efficiency assumptions, refer to Appendix B.

Water-related GHG emissions result from two main categories of energy use: a) system uses, including the supply, conveyance, distribution, and treatment of water and wastewater; and b) end uses, including all uses that occur within homes (e.g., water heating). RapidFire calculates energy use and emissions for system uses, while emissions resulting from end uses are accounted for as a component of residential and commercial building energy emissions. System uses are estimated on the basis of per-gallon water-energy intensity factors (expressed in kWh of electricity per million gallons) for Northern and Southern California as prepared in a 2006 study for the CEC (Navigant Consulting, Inc. 2006). The GHG emission rates for water-related electricity use are assumed to be the same as for building electricity use.

Retail water prices are applied on a per-acre foot basis, assuming a statewide baseline average cost for the year 2012, and a 1.1% price increase each year to 2050.[27] For price assumptions, refer to Appendix B. The resulting costs are included as a component of household expenditures.

4.3.4 Land Consumption

Land consumption includes all greenfield land that will be newly urbanized to accommodate population growth, including residential and employment areas, roadways, open space, and public lands. Refill growth occurs in already urbanized areas, so is not considered to be newly consumed land. The distribution of growth to greenfield or refill locations is set for each LDC in each scenario and represents a core assumption about future land use as shaped by plans and policies. The statewide scenarios

[26] While it would be ideal to project that water use patterns never return to previous levels, and some reduction is likely, the approach here considers demand as indicated by past typical irrigation needs as a baseline assumption.

[27] Because water rates vary significantly across the state, and in many areas have undergone changes in response to drought conditions, the baseline water cost is a rough estimate. The assumed 1.1% annual price increase is based on historic water-price surveys in California between 1991 and 2001 (Gleick, Cooley, & Groves 2005).

assume that all Urban growth occurs as refill, while most Standard growth occurs as greenfield. Compact growth occurs largely but not entirely as refill, with the proportions varying by scenario.

Acreage of greenfield land consumption is estimated on the basis of per-capita rates by LDC, which are calibrated using analyses of urbanized land within existing communities in California, and growth over time as indicated by California Department of Conservation data.[28]

4.3.5 Household Costs

Household costs include costs for passenger vehicle transportation, including fuels and auto ownership and maintenance, as well as utility costs for residential energy and water use. All scenarios assume the same prices for transportation fuels, electricity, natural gas, and water, which are projected to rise into the future. Costs are expressed in 2015 dollars.

4.3.6 Infrastructure Costs

To compare the cost and budget implications of varying scenarios and forms of development, RapidFire estimates the costs to build, operate, and maintain local infrastructure to serve new residential growth. Data from a number of local, regional, state, and utility sources were used to derive cost factors on a per-unit basis, with one-time capital costs and ongoing annual operations and maintenance (O&M) costs varying by housing type, LDC, and development condition (refill or greenfield).[29]

Capital costs for the following infrastructure elements are included: city costs for streets and transportation, water supply; sewage and wastewater, and local parks. O&M cost estimates include general fund spending for engineering and public works functions. Costs are expressed in 2015 dollars.

5. RESULTS

This section focuses on the results of most direct interest to policymakers. This section starts with some foundational results and then moves on to present three policy-relevant calculations. The results discussion is organized as follows:

1) Results with respect to how travel and building-related energy and resource demand unfold in the different scenarios.
2) Reassessment of the potential for land use to "close the gap" to reach the state climate policy goal for 2030, building on the E3 California PATHWAYS analysis.
3) Assessment of how land use could contribute to a 50% reduction in oil for motor vehicle transportation needs.

[28] California Department of Conservation, 2010. Farmland Mapping and Monitoring Program (FMPP) data. Available at www.conservation.ca.gov/dlrp/fmmp/Pages/Index.aspx. For further details about how land consumption is calculated in the RapidFire model, refer to the model documentation available at www.calthorpeanalytics.com.

[29] Calthorpe Analytics worked with the real estate, urban, and regional economics analysis firm Strategic Economics to develop the assumptions used in the infrastructure cost estimates. (Strategic Economics 2011)

4) Assessment of the level of SB 375-related VMT reductions, and associated environmental and economic impacts, estimated to result from the stronger land use scenarios developed for this study.

5.1 FOUNDATIONAL SCENARIO RESULTS

5.1.1 Transportation Impacts – Passenger Vehicle Travel

VMT results reflect changes in the demand for car travel that would follow from the different land use patterns. Average VMT per capita rises in the Past Trends scenario, and declines in each of the others. However, as population is projected to grow by 15%, all scenarios see a rise in total annual VMT, which amounted to approximately 275 billion miles driven in 2014.[30]

With its dispersed development patterns, the Past Trends scenario would result in the highest increase, to 334 billion by 2030. The Current Plans scenario would result in 317 billion, reflecting a slight decrease in average per-capita VMT from 2014, and a 13% decrease from 2005 that meets the statewide composite of the regional SB 375 targets.[31] The More Compact and Infill Focus scenarios go farther in lowering VMT, resulting in 289 and 279 billion miles, respectively. Table 4 shows the total and per-capita results. Compared to Past Trends, the Current Plans, More Compact, and Infill Focus scenarios result in 5%, 13%, and 16% lower VMT, respectively, in the year 2030.

Table 4. Annual VMT, total and per capita

	2005	2014	Past Trends 2030	Current Plans 2030	More Compact 2030	Infill Focus 2030
Total annual VMT (Billion miles)	292 B mi	275 B mi	334 B mi	317 B mi	289 B mi	279 B mi
VMT per capita (miles)	8,200 mi	7,200 mi	7,540 mi	7,160 mi	6,530 mi	6,310 mi

CARB's EMFAC model incorporates the latest statewide VMT estimates and projections. While EMFAC integrates future vehicle and fuel policies, it does not endogeously account for sensitivity to land use and travel demand management policies.

Figure 7 shows the estimated and projected VMT associated with the current (EMFAC 2014) and two previous (EMFAC 2011 and 2007) state forecasts, as well as the Past Trends scenario VMT result for comparison. In comparing the EMFAC VMT outputs over time, it is evident that historical estimates have been lowered (EMFAC 2014 calibrates VMT to fuel sales data), as have projections of VMT growth.

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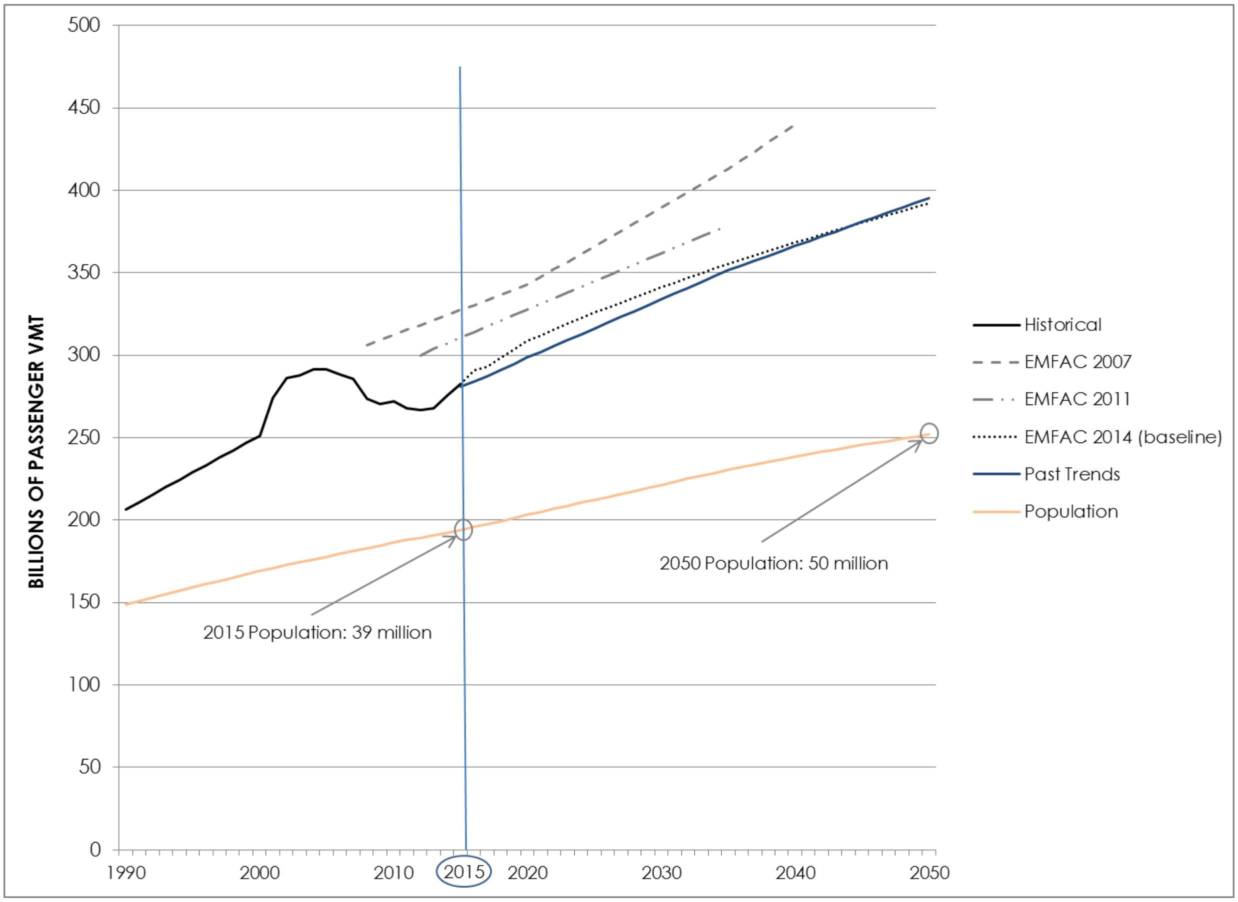
[30] ARB EMFAC 2014 statewide total for LDA, LDT1, LDT2, and MDV vehicle classes.

[31] VMT is projected forward from a year-2012 baseline that, in total and per capita, is lower than year-2005 VMT. VMT data from EMFAC 2014.

Figure 7. EMFAC VMT estimates and projections

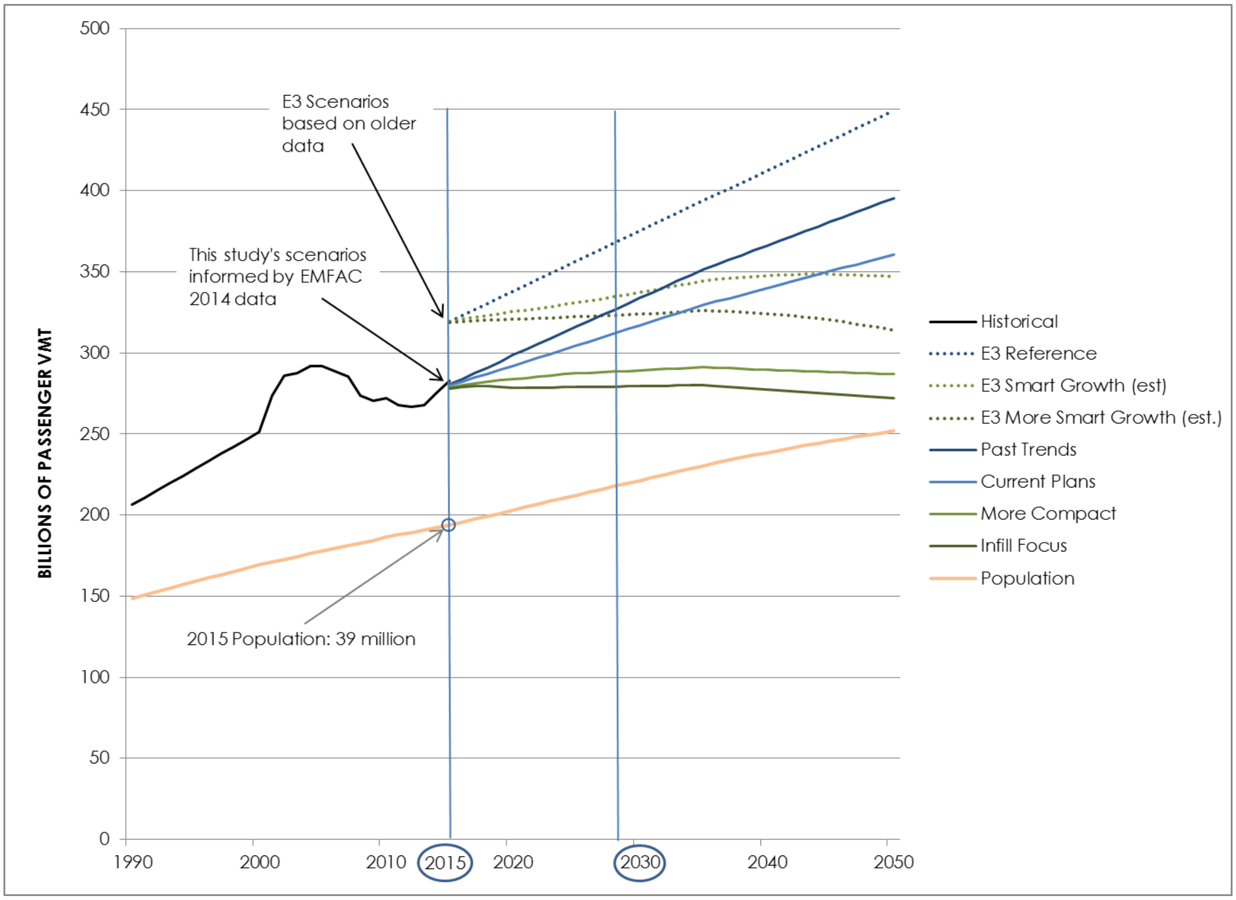


A central motivation of this work was to explore the role of land use in more depth than could be done under the broad scope of the E3 California PATHWAYS study (E3 2015a). This study also has the benefit of incorporating the newly released state transportation modeling data from EMFAC 2014, which includes updated historical VMT estimates. The latest EMFAC 2014 data had not been available at the time of the E3 analysis. Knowing that the EMFAC 2011 estimates were too high, E3 used data from the Energy Information Administration's (EIA) Annual Energy Outlook, scaling this national-level forecast down to the California state level (Mahone 2015). However, the recent historical and baseline scenario VMT numbers used by E3 are still high as compared to more recent estimates. For example, E3 reports a year-2010 figure of 315 billion miles for the passenger vehicle classes, while EMFAC 2014 reports 272 billion miles for that same year, a difference of about 10%.

Figure 8 shows this study's updated assumption regarding the current level of VMT in relation to the E3 work. In addition, the chart illustrates the wider range of impacts of the land use scenarios on VMT. In 2030, there is a 10% difference between the VMT assumptions applied by E3 in their scenarios. The E3 *Reference* VMT case was modeled in combination with the Reference energy technology scenario, while the *Smart Growth* VMT case was modeled in combination with their Early Deployment energy technology scenario. In comparison, we see a 16% difference between the Past Trends and Infill Focus scenarios. The E3 study indicates a 13% difference between the Reference case and the exploratory

More Smart Growth VMT case, though they do not present the emissions impacts of More Smart Growth in conjunction with the Early Deployment technology assumptions.

Figure 8. RapidFire VMT scenarios in comparison with those modeled in the E3 work



Transportation GHG Emissions

GHG emissions from passenger vehicles are determined by VMT, vehicle fleet mix and fuel economy, and the carbon intensity of the energy sources used to power the vehicles. Table 5 summarizes the results for each of the land use scenarios when paired with the energy technology assumptions of the E3 scenarios.

Table 5. Annual Transportation GHG Emissions, 2030 (MMT of CO_2e)

E3 technology scenario	1990	2012	Past Trends 2030	Current Plans 2030	More Compact 2030	Infill Focus 2030
(Historical)	108.4 MMT	117.0 MMT				
Reference			85.7 MMT	81.4 MMT	74.3 MMT	71.8 MMT
Straight Line			65.7 MMT	62.4 MMT	56.9 MMT	55.0 MMT
Early Deployment			57.8 MMT	54.9 MMT	50.1 MMT	48.4 MMT

For example, under E3's Reference scenario, which forecasts currently adopted policy (and the future technology trajectory expected as a result) for vehicles and low-carbon fuels, the Current Plans, More Compact, and Infill Focus scenarios would save 4.3 MMT of CO_2e, 11.4 MMT, and 13.9 MMT respectively, as compared to Past Trends. The implications of the GHG emissions results in the state policy context are discussed in Section 5.2.

5.1.2 Building Impacts – Residential and Commercial Energy Use

Causal pathways

The scenarios vary in their residential and commercial energy use profiles due to their building program – as represented by the mix of housing types for residential buildings and the mix of commercial building types associated with different development patterns – which results in varying amounts of commercial floor area built. Scenarios with higher proportions of more energy-efficient housing types like townhomes, apartments, and smaller lot single-family homes, as well as more compact commercial building types, require less energy to serve than those with higher proportions of larger lot single-family housing and more spacious commercial buildings. When combined with the effects of building efficiency and clean energy policies, how each scenario accommodates growth has a significant impact on resource consumption, costs, and GHG emissions.

Energy Use and Emissions

Assuming the E3 Reference case assumptions for energy efficiency, which project a moderate shift from electricity to gas use for the residential sector and modest improvements in electricity efficiency for the commercial sector, total annual energy use in 2030 ranges from 153,250 EJ (exajoules) for the Past Trends scenario to 146,600 EJ for the Infill Focus scenario, as shown in Table 6. While the absolute differences in energy use among scenarios vary along with the degree of energy efficiency achieved overall, the relative savings attributable to more compact building types are significant. Compared to Past Trends, the Current Plans, More Compact, and Infill Focus scenarios demand 1.5%, 3%, and 4.3% less energy, respectively.

While the relative differences in energy use among scenarios stem from the form of new growth, improving the energy efficiency of new and existing buildings reduces energy use overall. Successful implementation of energy efficiency measures, applied in the context of strategic land use planning for more space-efficient homes and commercial buildings, are needed to yield savings in line with our GHG reduction goals. The energy use results for the 2030 scenarios in combination with the E3 scenarios for building energy technology are summarized in Table 6.

Table 6. Annual energy use by land use and energy technology scenario, 2030 (exajoules)

	Past Trends	Current Plans	More Compact	Infill Focus
E3 Reference				
Residential Energy Use	87,900 EJ	86,800 EJ	85,300 EJ	84,600 EJ
Commercial Energy Use	65,400 EJ	64,500 EJ	63,600 EJ	62,000 EJ
Total Building Energy Use	153,300 EJ	151,300 EJ	148,900 EJ	146,600 EJ
E3 Straight Line				
Residential Energy Use	80,300 EJ	79,300 EJ	78,000 EJ	77,300 EJ
Commercial Energy Use	57,400 EJ	56,600 EJ	55,800 EJ	54,400 EJ
Total Building Energy Use	137,700 EJ	135,900 EJ	133,800 EJ	131,700 EJ
E3 Early Deployment				
Residential Energy Use	71,700 EJ	70,800 EJ	69,600 EJ	69,000 EJ
Commercial Energy Use	53,700 EJ	53,000 EJ	52,200 EJ	50,900 EJ
Total Building Energy Use	125,400 EJ	123,800 EJ	121,800 EJ	119,900 EJ

Building GHG Emissions

GHG emissions from building energy use vary according to baseline demand as impacted by building type, energy efficiency, and the resource mix of our energy portfolio. The scenario results highlight the need to achieve reductions through strategic actions on all fronts, including land use planning, energy efficiency, and the carbon intensity of the statewide energy portfolio. Table 7 summarizes the building sector GHG results for the 2030 scenarios in combination with the E3 energy scenarios.

Table 7. Annual building sector GHG by land use and energy technology scenario, 2030 (MMT CO_2e)

	Past Trends	Current Plans	More Compact	Infill Focus
E3 Reference				
Residential Energy GHG	47.8 MMT	47.2 MMT	46.5 MMT	46.1 MMT
Commercial Energy GHG	39.4 MMT	38.9 MMT	38.3 MMT	37.4 MMT
Total Building Energy GHG*	87.3 MMT	86.1 MMT	84.8 MMT	83.4 MMT
E3 Straight Line				
Residential Energy GHG	36.7 MMT	36.3 MMT	35.6 MMT	35.4 MMT
Commercial Energy GHG	26.7 MMT	26.4 MMT	26.0 MMT	25.3 MMT
Total Building Energy GHG	63.4 MMT	62.6 MMT	61.6 MMT	60.7 MMT
E3 Early Deployment				
Residential Energy GHG	29.5 MMT	29.1 MMT	28.6 MMT	28.4 MMT
Commercial Energy GHG	21.6 MMT	21.4 MMT	21.0 MMT	20.5 MMT
Total Building Energy GHG	51.1 MMT	50.5 MMT	49.6 MMT	48.9 MMT

** All figures are rounded, so totals may not match sum of residential and commercial components.*

5.1.3 Co-benefits

For straightforwardness of presentation, the following results are all derived using the E3 Reference case energy technology assumptions.

Air Pollutant Emissions and Public Health

Air Pollutant Emissions from Passenger Vehicles

Differences in VMT lead to different levels of air pollutants (including nitrogen oxides, carbon monoxide, sulfur dioxide, volatile organic compounds, and particulate matter) among the scenarios. CARB projects that rates of these pollutants will decline over time as vehicle technology improves. With reduced VMT, 2030 passenger vehicle pollutant emissions are 5%, 13%, and 16% lower in the Current Plans, More Compact, and Infill Focus scenarios, respectively, than in the Past Trends scenario.

Public Health Incidences and Costs

The results highlight the significant impact of land use on public health impacts. Relative to Past Trends, the Current Plans, More Compact, and Infill Focus scenarios reduce the total number of health incidences to 2030 by 5%, 13%, and 16%, respectively. In terms of health costs, cumulative savings for the scenarios as compared to Past Trends amount to $2.6 billion, $6.4 billion, and $8.2 billion to 2030, as shown in Table 8.

Table 8. Public health cost savings related to passenger vehicle transportation pollution, cumulative to 2030 (2015 dollars)

	Past Trends	Current Plans	More Compact	Infill Focus
Avoided health costs, cumulative through 2030 (2015 dollars, no discounting)	*(basis for comparison)*	$2.6 billion	$6.4 billion	$8.2 billion

Water Use Impacts

With moderate assumptions for water efficiency into the future, the Current Plans, More Compact, and Infill Focus scenarios, when compared to Past Trends, would save 1.1%, 2.6%, and 3.2% in annual residential water use, respectively, by 2030. The average new household in the More Compact scenario would use 22,000 fewer gallons of water per year by 2030 compared to Past Trends. This difference would amount to annual savings of over 124,000 acre feet by 2030, or nearly 1.3 million acre feet and $2.5 billion in cost savings, cumulatively.

Table 9. Annual residential water use, 2030

	Past Trends	Current Plans	More Compact	Infill Focus
Annual residential water use	4.82 million acre-feet	4.77 million acre-feet	4.70 million acre-feet	4.67 million acre-feet
Annual residential water use per new household	77,100 gal	67,800 gal	55,200 gal	49,800 gal

GHG Emissions from Water-Related Energy Use

Water-related GHG emissions vary across the scenarios with changes in water energy use and the rate of GHG emissions from electricity. Assuming the emissions rate of the Reference scenario, total emissions for the More Compact scenario are 3.2% lower than Past Trends in 2030; the results assume the same levels of efficiency achieved and thus highlight the impact of land use patterns and building program on this component of GHG emissions.

Table 10. Annual residential water-related energy use and emissions 2030

	Past Trends	Current Plans	More Compact	Infill Focus
Annual residential water-related electricity use	13,000 GWh	12,900 GWh	12,700 GWh	12,600 GWh
Annual residential water-related electricity emissions	3.09 MMT	3.05 MMT	3.01 MMT	2.99 MMT

Household Costs

Household costs vary based on VMT, energy, and water use. Assuming the Reference case assumptions with the same price projections into the future (in 2015 dollars) for all scenarios, the Past Trends scenario exhibits the highest costs per household for combined auto fuel, auto ownership and maintenance, and energy and water utilities costs. The Infill Focus scenario, with lower VMT and a more resource-efficient building program, saves households an average of nearly $2,000 per year compared to Past Trends. Over time, the savings in annual expenditures would amount to a significant sum for each household – money that could instead be applied to a home mortgage or other living expenses.

Table 11. Annual household auto and utility costs, 2030 (2015 dollars)

	Past Trends	Current Plans	More Compact	Infill Focus
Annual average fuel and auto costs per household	$11,600	$11,000	$10,100	$9,700
Annual average energy and water costs per household	$2,500	$2,450	$2,400	$2,400
Total annual average household costs	$14,100	$13,450	$12,500	$12,100

Land Consumption

The Past Trends scenario, which accommodates 70% of growth through 2030 in the Standard LDC, would require 850 square miles of greenfield land – 260 square miles more than that taken by the Current Plans scenario, which accommodates 50% of new growth in the Compact and Urban LDCs. With their focus on infill and redevelopment within existing urban areas and more compact forms of new growth, the More Compact and Infill Focus scenarios require even less greenfield land – 360 and 150 square miles, respectively.

Table 12. Greenfield land consumption to 2030

	Past Trends	Current Plans	More Compact	Infill Focus
Greenfield land consumption	850 sq mi	590 sq mi	360 sq mi	150 sq mi

Infrastructure Costs

Infrastructure costs, including the one-time capital expenditures and ongoing operations and maintenance costs to serve new residential growth, are higher in outwardly expansive scenarios, particularly those that feature a significant amount of larger lot single-family construction. Increased land consumption leads to higher costs for local and sub-regional infrastructure, as new greenfield development requires significant capital investments in new local roads, water and sewer systems, and parks. Conversely, growth focused in existing urban areas takes advantage of existing infrastructure and capitalizes on the efficiencies of providing service to higher concentrations of housing and jobs.[32]

Operations and maintenance (O&M) costs include the ongoing city General Fund expenditures required to operate and maintain the infrastructure serving new residential growth. These engineering and public works costs are strongly linked to the physical form of infrastructure. More dispersed development, which entails greater lengths of roads and sewer pipes, incurs higher costs to local jurisdictions than more compact development, which capitalizes on the economic efficiencies of shared infrastructure capacity. Compared to the Past Trends scenario, local and sub-regional infrastructure cost savings add up to a cumulative savings to 2030 of $9.3 billion, $12.4 billion, and $18.5 billion for the Current Plans, More Compact, and Infill Focus scenarios, respectively.

Table 13. Local infrastructure costs to 2030 (including capital, operations, and maintenance costs)

	Past Trends	Current Plans	More Compact	Infill Focus
Capital costs	$61.3 billion	$53.5 billion	$51.9 billion	$46.7 billion
Operations and maintenance costs	$15.8 billion	$14.3 billion	$12.8 billion	$11.9 billion
Total local infrastructure costs*	$77.1 billion	$67.7 billion	$64.6 billion	$58.6 billion

** All figures are rounded, so totals may not match sum of component costs.*

Co-benefits Summary

Table 14 summarizes the 2030 co-benefit assessments in terms of their impacts relative to the Past Trends scenario, assuming the E3 Reference case technology assumptions where applicable. The table shows the impressive array of "co-benefits" beyond carbon emission reductions that smarter land use promises. In the environmental realm, in addition to the global climate benefit, smarter land use planning results in local air quality benefits, reductions in water use, and reductions in land demanded for the footprint of our cities. In socio-economic terms, we also quantify improved health outcomes and savings on health care costs due to cleaner air, the savings for local government due to less need to build new infrastructure thanks to more focused development patterns, and savings for households due to less spending on auto-related travel demand.

[32] A recent study by Smart Growth America (2013) comprehensively examines the fiscal benefits of compact development through a number of studies across the country.

Table 14. Co-benefit impacts in 2030, annual and cumulative

	Current Plans	More Compact	Infill Focus
Economic impacts quantified (2015$)			
Household cost savings			
Cumulative to 2030	$79 billion	$196 billion	$250 billion
Annual per average household in 2030	$600	$1,600	$2,000
Avoided public health costs			
Cumulative to 2030	$2.6 billion	$6.4 billion	$8.2 billion
Annual in 2030	$320 million	$850 million	$1,040 million
Infrastructure cost savings			
Cumulative to 2030	$9.3 billion	$12.4 billion	$18.5 billion
Environmental impacts quantified			
Criteria pollutant emissions avoided			
Cumulative to 2030	217,000 tons	532,000 tons	686,000 tons
Annual in 2030	19,000 tons	50,000 tons	61,000 tons
Residential water savings			
Cumulative to 2030	540,000 acre-feet	1.28 mil acre-feet	1.59 mil acre-feet
Annual avg per new household in 2030	9,300 gallons	21,900 gallons	27,300 gallons
Land conservation			
Cumulative to 2030	270 sq mi	490 sq mi	700 sq mi

While the 2030 impacts are large, the benefits accrue substantially over time. Table 15 summarizes the 2050 results. (Avoided public health costs are not projected for 2050 because the valuation study we are using to assign damages to criteria pollutants does not extend as far as 2050.)

Table 15. Co-benefit impacts in 2050, annual and cumulative

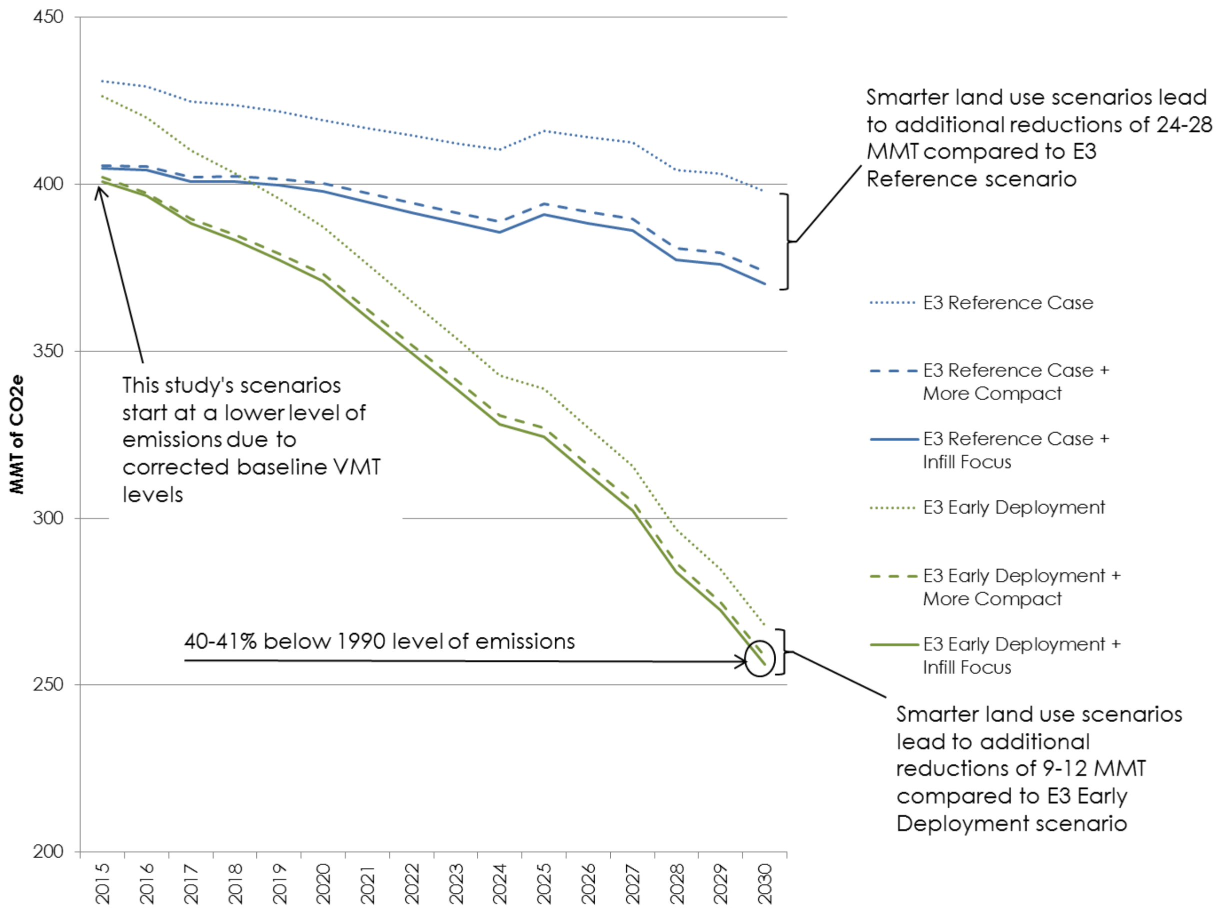
	Current Plans	More Compact	Infill Focus
Economic impacts quantified (2015$)			
Household cost savings			
Cumulative to 2050	$370 billion	$1.0 trillion	$1.2 trillion
Annual per average household in 2050	$1,100	$3,500	$4,000
Infrastructure cost savings			
Cumulative to 2050	$17.8 billion	$25.6 billion	$37.4 billion
Environmental impacts quantified			
Criteria pollutant emissions avoided			
Cumulative to 2050	600,000 tons	1.66 million tons	2.00 million tons
Annual in 2050	21,000 tons	66,000 tons	75,000 tons
Residential water savings			
Cumulative to 2050	1.87 mil acre-feet	4.42 mil acre-feet	5.51 mil acre-feet
Annual avg per new household in 2030	7,100 gallons	16,800 gallons	20,900 gallons
Land conservation			
Cumulative to 2050	520 sq mi	960 sq mi	1,380 sq mi

5.2 THE STATEWIDE 2030 TARGET FOR GREENHOUSE GAS EMISSIONS

Having explored detailed results across scenarios, we next analyze the carbon implications of our work on land use in relation to the E3 California PATHWAYS study. We focus on the incremental carbon difference between the E3 scenarios and the land use scenarios developed for this study. Each of the E3 scenarios hits the 2050 target, but they fall short for 2030. The E3 work demonstrated a maximum emission reduction of 38% by 2030, two percentage points less than the Governor's goal. We address the question: what are the prospects for achieving the Governor's 2030 goal with the same energy assumptions, and smarter land use?

The 2030 results, as illustrated in Figure 9 and summarized in Table 16 indicate that the More Compact and Infill Focus scenarios reach 40% and 41% below 1990 emissions, respectively – in line with the proposed target. The results also illustrate the principle of ordering in climate policy analysis. If the best land use scenario is paired with the aggressive E3 Early Deployment scenario, then the apparent impact is much smaller than if smart growth policy is considered in light of current policies. The Infill Focus scenario decreases 2030 emissions by 28 MMT of CO_2e if assuming E3 Reference case assumptions, but with the more progressive assumptions for low-carbon fuel and more efficient vehicles of the Early Deployment scenario, the incremental difference is 11 MMT. The additional avoided emissions under the More Compact and Infill Focus land use scenarios developed for this study stem primarily from differences in passenger VMT, with some savings also attributable to reduced building energy demand. The results demonstrate that smart land use could be the deciding factor in whether or not California is able to achieve its 2030 decarbonization target.

Figure 9. GHG emissions to 2030 for E3 scenarios and updated land use scenarios



The total emissions implied for 2015 are likely too low in light of estimated 2013 statewide emissions (the most recent data), which totaled 459 MMT of CO_2e. We hypothesize that our correction of the VMT baseline issue in the E3 study induces this effect. The E3 study's higher baseline VMT was counterbalanced by a combination of factors related to fuel carbon intensity and vehicle efficiency. Since we have only corrected for VMT, these other fuel and vehicle assumptions are carried forward. By maintaining the E3 fuel and vehicle assumptions, the results may slightly undercount the carbon reductions and co-benefits of smart growth.

The statewide GHG reductions achievable beyond the E3 California PATHWAYS results are summarized in Table 16. These reductions are attributable to the VMT and building energy demand results of the land use scenarios in combination with the E3 technology scenarios as shown. When E3's Early Deployment technology assumptions are applied with the Infill Focus land use scenario, overall reductions amount to 41% below 1990 emission levels (as indicated in the result at the bottom-right corner of the table).

Table 16. 2030 statewide carbon analysis in relation to E3 study

Technology assumptions	Land use scenario	Additional CO_2e savings as compared to E3 Smart Growth result	Additional CO_2e savings as a % of 1990 emissions (431 MMT)	E3 scenario total GHG reduction from 1990 (with E3 Smart Growth land use)	GHG reductions from 1990 (E3 scenario total reduction plus increment from this study's land use scenario)
E3 Reference	Current Plans	-5.1 MMT	-1.2%	-8%	-9%
	More Compact	-13.6 MMT	-3.2%	"	-11%
	Infill Focus	-17.5 MMT	-4.1%	"	-12%
E3 Straight Line	Current Plans	-4.5 MMT	-1.0%	-33%	-34%
	More Compact	-11.0 MMT	-2.5%	"	-35%
	Infill Focus	-13.8 MMT	-3.2%	"	-36%
E3 Early Deployment	Current Plans	-3.0 MMT	-0.7%	-38%	-39%
	More Compact	-8.6 MMT	-2.0%	"	**-40%**
	Infill Focus	-11.1 MMT	-2.6%	"	**-41%**

The emissions reductions seen with the Current Plans, More Compact, and Infill Focus scenarios are largely attributable to the lower modeled VMT of our study's scenarios as compared to the E3 Smart Growth VMT assumptions (differences in building energy demand play a smaller role). Figure 10 illustrates the VMT differences behind the additional 9-11 MMT in CO_2e reductions (equivalent to 2%-2.6% of 1990 emissions) as compared to the E3 results.

Figure 10. VMT differences contributing to additional CO_2e savings

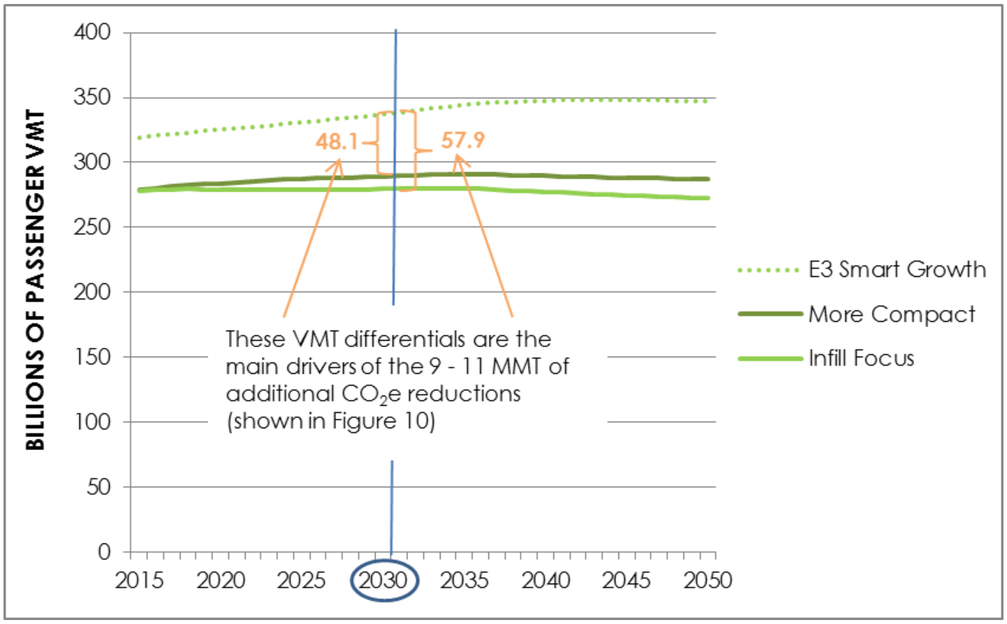


Table 17 summarizes the scenario results for additional CO_2e savings for the years 2020 and 2050. By 2050, the extent of the additional savings under the E3 Straight Line and Early Deployment scenarios are relatively minimal due to the vast improvements in vehicle fuel economy, the carbon content of fuels, and improvements in energy efficiency and the energy portfolio. These results underscore the importance of the interim-year targets to ensure progress in land use planning and technological advancements, and reducing emissions along the way. As is becoming widely recognized, the path to achieving the target in 2050 is as important as meeting the target itself.

Table 17. 2020 and 2050 statewide carbon impacts in relation to E3 study

		2020		2050	
Technology assumptions	Land use scenario	Additional CO_2e savings as compared to E3 Smart Growth result	Additional CO_2e savings as a % of 1990 emissions (431 MMT)	Additional CO_2e savings as compared to E3 Smart Growth result	Additional CO_2e savings as a % of 1990 emissions (431 MMT)
E3 Reference	Current Plans	-8.2 MMT	-1.9%	1.1 MMT	0.3%
	More Compact	-11.7 MMT	-2.7%	-14.7 MMT	-3.4%
	Infill Focus	-14.0 MMT	-3.2%	-19.8 MMT	-4.6%
E3 Straight Line	Current Plans	-8.1 MMT	-1.9%	0.1 MMT	0.0%
	More Compact	-11.4 MMT	-2.7%	-1.0 MMT	-0.2%
	Infill Focus	-13.7 MMT	-3.2%	-1.6 MMT	-0.4%
E3 Early Deployment	Current Plans	-7.8 MMT	-1.8%	0.1 MMT	0.0%
	More Compact	-11.2 MMT	-2.6%	-0.6 MMT	-0.1%
	Infill Focus	-13.3 MMT	-3.1%	-1.2 MMT	-0.3%

5.3 50% LESS PETROLEUM FOR MOTOR VEHICLE USE

Our analysis of the potential for oil use reductions for motor vehicle transportation in 2030 pertains to the passenger vehicle segment, which makes up 77% of all on-road transportation emissions. Our analysis indicates that a 2% reduction from today's total VMT would accomplish a 50% reduction in oil use when the E3 Early Deployment scenario is used for other assumptions. Under the Infill Focus scenario, total VMT in 2030 rises by about 1% from today's level while population increases by 14%. Though a reduction of 2% below today's total VMT level is slightly higher than that of any of the scenarios we model, we would expect such an outcome to be achievable in combination with other evolving mobility options, such as ride-hailing companies (e.g., Uber, Lyft), micro-transit (private companies operating like public transit agencies over smaller areas, e.g., Chariot), bike sharing and e-bikes, and investments in safe active transportation infrastructure (i.e., to support cyclists and pedestrians). These emerging transportation choices fit well with more compact and mixed land use patterns where homes, services, and jobs are nearby.

5.4 SB 375

CARB's implementation of SB 375 is in the midst of a reassessment of the law's GHG reduction targets. Current 2020 and 2035 targets appear well within reach, given the trajectory of current regional plans and supportive state policy with SB 375 and SB 743. Our analysis offers a chance to assess the impacts of stronger targets.

The results show that the Current Plans scenario almost doubles the targeted per-capita VMT reductions in 2020 (12% reductions compared to 7%), and reaches the SB 375 goal of a 13% reduction below 2005 per-capita VMT in 2035.[33] The More Compact and Infill Focus scenarios would yield reductions of 15% and 16%, respectively, below the 2005 VMT per capita level in 2020, and reductions of 23% and 26%, respectively, in 2035.

Historical data shows that VMT and emissions were near their peak in 2005. Table 18 compares VMT data for past years and scenario projections. Per capita VMT in 2014 was already 12% below the 2005 level. Credit is due for planning activities to date, and for the creation of mechanisms to enable coordination across jurisdictions. But more can and should be done, to great positive effect.

Table 18. VMT per capita, historical and projected for the years 2020 and 2035

	1990	2005	2014	2020		2035	
	VMT per capita	*VMT per capita*	*VMT per capita*	*VMT per capita*	*% below 2005*	*VMT per capita*	*% below 2005*
Historical	7,540 mi	8,200 mi	7,200 mi				
SB 375 composite statewide target				7,630 mi	*7%*	7,130 mi	*13%*
Past Trends				7,350 mi	*10%*	7,630 mi	*7%*
Current Plans				7,180 mi	*12%*	7,150 mi	*13%*
More Compact				6,980 mi	*15%*	6,320 mi	*23%*
Infill Focus				6,850 mi	*16%*	6,080 mi	*26%*

**Figures rounded to three significant figures. Percentages based on values before rounding.*

Table 19 offers a look at the carbon reductions and co-benefits that could be achieved in moving beyond Current Plans to the More Compact or Infill Focus scenarios.

[33] In the context of SB 375 analysis, the per-capita VMT reductions are taken to correspond directly with per-capita GHG reduction targets. This isolates the impacts of land use and transportation strategies from those attributable to technological vehicle and fuel advancements that reduce transportation emissions rates.

Table 19. 2035 carbon and co-benefit impacts as compared to Current Plans scenario (assuming E3 Reference case technology scenario). Annual values, except when noted.

	More Compact vs. Current Plans	**Infill Focus vs. Current Plans**
CO_2e emissions from passenger transportation and residential and commercial building energy use sectors	-10.4 million metric tons	-14.5 million metric tons
Residential water use	-83,900 acre-feet	-120,000 acre-feet
Residential water use per new household	-11,600 gallons	-16,600 gallons
Residential water-related electricity use	-12,000 Gigawatt hours	-11,900 Gigawatt hours
Residential water-related electricity emissions	-52,000 metric tons	-74,000 metric tons
Average household costs	-$1,300	-$1,700
Greenfield land consumption (cumulative to 2035)	-290 sq mi	-560 sq mi

6. POLICY RECOMMENDATIONS

The results of the analysis conducted for this report point to the feasibility of the proposed 2030 emissions reduction target of 40% below 1990 emissions, and indicate that **implementation of smart land use policy could be the deciding factor in meeting the 2030 target**. Our results further show that the significant emissions reductions delivered by smart growth will bring wide-ranging economic and environmental co-benefits. Along with reducing climate-changing carbon emissions, smart growth also delivers an impressive array of co-benefits: cleaner air, improved public health outcomes, lower water use, cost savings for households, reduced dependency on oil, more efficient provision of public infrastructure, reduced congestion, and the preservation of natural and working lands, which provide carbon sequestration and other ecosystem services. Smart growth will help expand the supply of housing most in demand as people increasingly want to live closer to work in walkable neighborhoods that are well served by transit (Nelson 2011).

We recommend that CARB strengthens emissions reduction targets under SB 375 as part of a 2030 Scoping Plan. The State should complement these targets with substantial funding to support cities and regions so they successfully implement land use plans that help meet those targets.

INCREASED STATE SUPPORT FOR SB 375 IMPLEMENTATION

With SB 375, the state tasks its regions with developing land use plans and coordinated transportation investment packages that reduce carbon emissions from passenger vehicle travel. MPOs face the challenge of implementing land use plans and strategies that reduce passenger VMT without explicit authority to regulate land use, and with limited funding. These regional land use plans, embodied within the MPOs' state-required Sustainable Community Strategies (SCSs), need to be linked to relevant and effective funding incentives and other policy measures that encourage or enforce implementation of the SCS at the local jurisdiction level. This is where a state role, and particularly the use of funding and performance criteria, is so important.

Expand funds to facilitate SCS implementation. The state should facilitate SCS implementation by expanding funds for land use plans, projects, and infrastructure investments that are consistent with the SCSs and thus with GHG reduction goals. This should include any new transportation and housing investments the state undertakes.

The state can also distribute funds to MPOs to support SCS implementation and to expand the types of programs listed in the recommendations that follow.

Link state funding to high performance zones, as designated by RTPs/SCSs. One way that the state can most easily support the implementation of compact land use plans and policies is by prioritizing existing funding for plans, projects, and infrastructure in and around high performance zones designated in adopted RTP/SCS plans. These areas go by a number of names – Priority Development Areas (PDAs), High Quality Transit Areas (HQTAs), Transit Priority Areas (TPAs), and others – and serve as the foundation for compact land use planning in the SCS plans. Steering higher proportions of population and job growth away from agricultural lands and open space and into these zones can require updated or new general plans, specific plans, and other policies, as well as upgraded transportation, sewer and water, and other infrastructure improvements.

Additional funding for such activities is particularly urgent given the 2011 dissolution of redevelopment funding, which had supported a proportion of infill and compact growth across the state's urban areas. Successful and innovative programs like the Southern California Association of Governments (SCAG) Compass Blueprint program and the Metropolitan Transportation Commission (MTC) OneBayArea Grant Program support these activities, but are not big or far-reaching enough to support the full implementation of the SCS plans, particularly in light of the Governor's 2030 target directives.

One example of how funds can be targeted is the Strategic Growth Council's Affordable Housing and Sustainable Communities program. It directs housing and infrastructure growth to areas expecting the most growth, while also funding improved infrastructure to ensure that other areas gain that capacity for compact growth in the future. Moreover, this year it will set aside at least 10% for a rural innovation fund. More dedicated state funding from cap-and-trade, other new funds, or by prioritizing existing funds could significantly further compact land planning activities across all the State's regions. California's carbon levels, air quality, public health, and water challenges are dependent on such funding prioritization.

Support planning, research and data development that facilitates more integrated land use plans and policies. There needs to be a consistent, defensible, and robust set of methods for measuring GHG and co-benefits performance. Data and analytical capabilities are evolving quickly, and we are still learning about the strategies that bring about the biggest GHG benefits, and in turn provide the most co-benefits. To make the most efficient use of the State's investments there should be substantial new resources to improve planning and modeling at all levels. Improved tools and standardized methods and assumptions will allow MPOs and the state to analyze plans, investments, and large projects based on GHG and co-benefit performance (or target attainment). This planning and analytical capacity involves more people and requires more granular data and modeling, thus necessitating more resources to be done well.

7. CONCLUSION

Building mostly within our existing urban boundaries will not be simpler, but it will pay off with economic, environmental, and social benefits. The smarter growth patterns modeled in this study deliver more transportation choices, better mobility, and an upgraded quality of life for millions of Californians. This report quantifies the carbon emissions reductions and a selection of the co-benefits associated with smarter development. The land use patterns studied here could lead to even larger carbon emissions reductions than estimated because they will also preserve more land in California for carbon sequestration.

In conjunction with technological innovation, comprehensive land use planning is crucial to meeting the larger goals for economy-wide emissions reduction and reducing oil consumption by 50%. CARB should set stronger SB 375 goals that are consistent with the Governor's Executive Order to reduce statewide carbon emissions 40% below 1990 levels by 2030. CARB should also set stronger requirements for smart growth actions by local governments to qualify for funding from the cap-and-trade program's auction revenues.

California's population is expected to hit 50 million by 2050, up from 39 million today. As the state's population and economy expand, it is vital to consider future growth patterns and their implications. Land use patterns, once established, are long-lasting and can be costly to reverse or retrofit. Rather than emphasize the downside of past patterns, this report focuses on the potential upside to redoubled smart growth efforts. There is a golden growth opportunity to be seized. The state should further advance its efforts to encourage patterns that will help meet its health, climate, energy, water, and fiscal challenges. The world's cities, like California's, are surging with energy, drawing new residents, and driving innovation and growth. California, as a policy leader and America's most urbanized state, is poised to help advance and benefit from this new age of enlightened urbanism.

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APPENDIX A

This appendix explains the efforts taken to align the assumptions used in this analysis with E3's research (E3 2015a). We have endeavored to align maximally with the E3 analysis that was conducted on behalf of the state energy agencies (California Air Resources Board, California Energy Commission, California Independent System Operator, and the California Public Utilities Commission) for three reasons: 1) the E3 study was commissioned by the policymakers themselves; 2) it provides a careful and detailed technological treatment in the E3 California PATHWAYS work, and 3) by building on this E3 analytical foundation, we can reduce misunderstanding due to misaligned assumptions, and instead focus on the core cause-effect dynamics under study in this research.

This study's results for energy use and emissions from the transportation and building energy sectors reflect the application of assumptions intended to reflect the E3 California PATHWAYS scenarios. The assumptions were derived using the information E3 made available, with some guidance along the way in the form of answers to specific questions. In turn, the assumptions were applied to the vehicle-miles traveled (VMT) and building energy use outputs produced for a range of land use scenarios using Calthorpe Analytics' RapidFire sketch model.

TRANSPORTATION ENERGY USE AND EMISSIONS ASSUMPTIONS

Detailed vehicle stock and performance data from the E3 scenarios were used to estimate vehicle performance, transportation energy and fuel use, and corresponding emissions assumptions.

Vehicle Stock Assumptions

- Vehicle classes included: LDV and MDV autos and light trucks, in accordance with the vehicle classes covered by SB 375.
- All vehicle technology types were included: gasoline, diesel, CNG, diesel hybrids, PHEVs, BEVs, and hydrogen fuel cell vehicles.
- E3's vehicle stock counts and new vehicle performance (in miles per gallon of gas equivalent, or miles/GGE for each year to 2050 were used to calculate on-road vehicle performance assumptions by vehicle technology, by year. These rates were in turn applied to VMT by vehicle type, assuming a direct relationship between VMT and vehicle stock.
- The following table shows the resulting combined fleet average performance assumptions, in terms of miles/GGE, over time. (The averages are not applied directly to VMT, but were calculated to see the variation among the scenarios.)

	Baseline Fleet Average GGE	Reference Fleet Average GGE	Straight Line Fleet Average GGE	Early Deployment Fleet Average GGE
2012	23.5	23.5	23.5	23.5
2020	27.0	26.9	26.7	27.6
2030	36.6	37.0	43.3	46.2
2035	41.2	41.6	56.9	60.0
2050	52.5	53.2	95.7	95.6

Vehicle Performance Assumptions

- Vehicle performance expressed in miles/GGE produce transportation energy use results in GGE by vehicle technology type.

- Emissions per GGE are used to estimate emissions for liquid fuels, with gasoline and diesel emissions starting at 2012 baseline EMFAC rates. Emissions rates for gasoline and diesel in the E3 scenarios are projected based on the carbon/energy content of fuel, and the given percentage of biofuels (with zero emissions) used into the future.

- Emissions from electricity used by BEVs and PHEVs (for the assumed percentage of total PHEV miles) is calculated by first converting miles/GGE for those vehicle types to miles/kWh. Then, an energy conversion factor, assumed to be 33.71 kWh/GGE (US EPA 2015, p.100), is applied.

- Estimating hydrogen fuel cell vehicle emissions also required imputation. The approach builds on the fact that hydrogen is only used for transport, and the given fraction of the fleet that is hydrogen fuel cell. Using that percentage, and multiplying by total VMT results in the fraction of miles traveled by hydrogen/fuel cell vehicle. Emissions associated with hydrogen production are then divided by the number of miles to get emissions per mile.

Liquid Fuels Assumptions

- Emissions per gallon of gasoline and diesel in each year, for each technology scenario, were estimated using the outputs for energy GHGs given in the “Compiled Results” spreadsheet in the E3 Main Outputs workbook. Given that the emissions rates per gallon remain the same over time for the Baseline scenario, and that each ‘base’ technology scenario reflects the impacts of the same amount of travel, we assume that comparing the total GHG output figure for a given scenario and year with the output figure for the Baseline scenario in that year results in a percentage difference that is representative of the emissions rate reduction relative to the baseline. Further information on the calculations as applied to the E3 output data can be provided upon request.

- In turn, the percentage reductions are applied to the baseline 2010 emissions rates for gasoline and diesel to estimate emissions rates for each scenario and year. The baseline 2010 emissions rates are based on assumed fuel carbon intensity for gasoline and diesel as indicated by data from the Environmental Protection Agency (EPA) and Energy Information Administration (EIA).
- Non-energy emissions associated with fuels are also included.

BUILDING ENERGY USE AND EMISSIONS ASSUMPTIONS

Energy efficiency assumptions

Emulating the E3 scenarios for building energy efficiency required translation of their study's energy technology assumptions as applied to residential and commercial buildings into the RapidFire model framework. RapidFire applies energy efficiency assumptions at the unit level (per household or per commercial square foot), rather than in terms of aggregate technology saturation. Rather than step through the bundled technology measures for each scenario, we used the E3 PATHWAYS main outputs data (from the Compiled Results tab of the Main Outputs spreadsheet) to evaluate the bottom-line electricity and natural gas savings by scenario and by year resulting from the study's assumptions about technology distribution and demand changes over time. This involved:

- Imputing electricity use per household and commercial square foot based on given household (HH) and commercial costs, and retail electricity cost, by scenario and year. This yields a percentage reduction or percentage growth in per-household use from our base year of 2012, as shown in Table B1.
- Calculating total electricity use based on per-household factor and household counts, as given in the E3 Macro Inputs spreadsheet.
- Calculating total natural gas use by subtracting total electricity use from total residential energy use. In the process we converted between kWh and exajoules, and therms and exajoules.
- Calculating natural gas use per household by dividing by the household counts. This yields a percentage reduction or percentage growth in per-household use from our base year of 2012, as shown in Table B1. Table B2 shows the resulting proportion for electricity demand in the overall fuel mix.

Table B1. Residential and commercial energy savings assumptions

	Baseline	Reference	Straight Line	Early Deployment
RESIDENTIAL ENERGY SAVINGS per HH				
Residential Electricity, 2020	14%	16%	17%	16%
Residential Electricity, 2030	9.8%	1.4%	15%	33%
Residential Electricity, 2035	2.5%	-4.7%	26%	35%
Residential Electricity, 2050	3.1%	-19.6%	33%	39%
Residential Natural Gas, 2020	-11%	-16%	-21%	-23%
Residential Natural Gas, 2030	-12%	-24%	-44%	-68%
Residential Natural Gas, 2035	-8.4%	-25%	-67%	-83%
Residential Natural Gas, 2050	-7.6%	-22%	-95%	-100%
Residential Energy Total, 2020	*-2.1%*	*-4.5%*	*-7.2%*	*-9.0%*
Residential Energy Total, 2030	*-4.4%*	*-15%*	*-23%*	*-32%*
Residential Energy Total, 2035	*-4.5%*	*-18%*	*-34%*	*-41%*
Residential Energy Total, 2050	*-3.8%*	*-21%*	*-50%*	*-50%*
COMMERCIAL ENERGY SAVINGS per sq ft				
Commercial Electricity, 2020	-8.9%	-11%	-18%	-17%
Commercial Electricity, 2030	-9.0%	-20.6%	-22%	-20%
Commercial Electricity, 2035	-9.3%	-25.1%	-20%	-13%
Commercial Electricity, 2050	-7.8%	-25.0%	-7.5%	-5.3%
Commercial Natural Gas, 2020	9.4%	7.6%	9.6%	0.8%
Commercial Natural Gas, 2030	6.1%	-2.7%	-41%	-70%
Commercial Natural Gas, 2035	7.2%	2.3%	-72%	-100%
Commercial Natural Gas, 2050	6.9%	-7.8%	-100%	-100%
Commercial Energy Total, 2020	*-4.6%*	*-7.1%*	*-11.5%*	*-12.5%*
Commercial Energy Total, 2030	*-5.5%*	*-16%*	*-27%*	*-31%*
Commercial Energy Total, 2035	*-5.4%*	*-19%*	*-32%*	*-36%*
Commercial Energy Total, 2050	*-4.4%*	*-21%*	*-42%*	*-43%*

Table B2. Resulting proportion of electricity in fuel mix

	Baseline	Reference	Straight Line	Early Deployment
RESIDENTIAL ENERGY FUEL MIX, total				
Residential Electricity %, 2012	*36%*	*36%*	*36%*	*36%*
Residential Electricity %, 2020	*42%*	*43%*	*45%*	*45%*
Residential Electricity %, 2030	*41%*	*42%*	*53%*	*70%*
Residential Electricity %, 2035	*38%*	*41%*	*68%*	*82%*
Residential Electricity %, 2050	*38%*	*36%*	*94%*	*100%*
COMMERCIAL ENERGY FUEL MIX, total				
Commercial Electricity %, 2012	*77%*	*77%*	*77%*	*77%*
Commercial Electricity %, 2020	*73%*	*73%*	*71%*	*73%*
Commercial Electricity %, 2030	*74%*	*73%*	*81%*	*90%*
Commercial Electricity %, 2035	*74%*	*71%*	*90%*	*100%*
Commercial Electricity %, 2050	*74%*	*73%*	*100%*	*100%*

Application of efficiency assumptions in RapidFire

The RapidFire model assumes that per-unit residential energy demand varies by building type: single-family detached large lot (with unit sizes over 2,000 square feet), single-family detached small lot (unit sizes under 2,000 square feet), townhome, and multifamily. The baseline figures are derived from CEC Residential Appliance Saturation Study (RASS) data. The model also differentiates between existing and new homes.

To reflect the translated assumptions above, the efficiency assumptions for existing and new homes were calibrated to meet the average reductions given a reference case housing growth scenario. This scenario assumes that the distribution of housing by type stays mostly stable, with some single-family detached being replaced by townhomes and multifamily as indicated in the E3 analysis. The same total projections for household growth were used. The RapidFire land use scenarios then vary further in energy use as a function of their housing type mix, with more compact scenarios including greater proportions of small lot, townhome, and multifamily units.

Also, given the size of the existing building population relative to new growth, there's a heavy burden on existing buildings to achieve energy savings. The target reductions, or fuel switch capacity, that we assume for existing buildings are not as deep as for new construction, but they do approach them in the Straight Line and more progressive scenarios.

On the commercial side, average per-square foot electricity and natural gas factors are used across all floorspace/employment categories. A similar approach for calibrating assumptions for existing vs. new building populations was applied, using the E3 commercial floorspace projection as a reference case. The amount of commercial floorspace into the future varies among the land use scenarios in RapidFire, though, as growth is projected in Urban vs. Compact vs. Suburban areas and corresponding building types.

Energy use baselines

The baselines estimated from the E3 output data were generally consistent with statewide average factors derived from RASS data, providing the assurance that the RASS factors could be applied in a comparative analysis. The residential and commerical baseline energy use factors are summarized in Appendix B.

Electricity and natural gas emissions assumptions

Emissions rates per MWh of electricity use and therm of natural gas use, by technology scenario, were directly extractable from the E3 Main Outputs spreadsheet.

APPENDIX B

This appendix summarizes the input assumptions applied to the land use scenarios in RapidFire.

Assumption	Description	Base Year	2020	2030	2035	2050
TRANSPORTATION						
Fuel economy	Average on-road fuel economy for SB 375 vehicle classes (LDA, LDT1, LDT2, MDV) by vehicle type, miles per gallon of gasoline equivalent (mpgge)					
	Baseline	23.5	27.0	36.6	41.2	52.5
	Reference	23.5	26.9	37.0	41.6	53.2
	Straight Line	23.5	26.7	43.3	56.9	95.7
	Early Deployment	23.5	27.6	46.2	60.0	95.6
Fuel price	Statewide average per gallon of liquid fuel, 2015 dollars	$3.39	$3.32	$3.73	$3.94	$5.07
Auto ownership and maintenance cost	Cost per mile for auto ownership and maintenance	$0.40	$0.40	$0.40	$0.40	$0.40
Transportation emissions, gasoline	Pounds of CO_2e per gallon (tank-to-wheel emissions only)					
	Baseline	19.6	19.6	19.6	19.6	19.6
	Reference	19.6	18.4	17.7	17.4	17.1
	Straight Line	19.6	18.1	14.6	11.6	1.3
	Early Deployment	19.6	17.9	13.6	10.3	0.1
Transportation emissions, diesel	Pounds of CO_2e per gallon (tank-to-wheel emissions only)					
	Baseline	22.4	22.4	22.4	22.4	22.4
	Reference	22.4	22.4	22.4	22.4	22.4
	Straight Line	22.4	19.4	9.7	4.6	0
	Early Deployment	22.4	18.51	2.14	0	0
Transportation emissions, electricity	Pounds of CO_2e per kilowatt-hour (same as for building electricity)					
	Baseline	0.60	0.60	0.60	0.60	0.60
	Reference	0.60	0.52	0.37	0.30	0.45
	Straight Line	0.60	0.51	0.32	0.27	0.11
	Early Deployment	0.60	0.52	0.37	0.30	0.11
Transportation electricity price	Price per kilowatt-hour (same as for building electricity)	$0.15	$0.17	$0.18	$0.19	$0.25

Assumption	Description	Base Year		2020	2030	2035	2050
BUILDINGS							
Energy use of new buildings	Statewide average energy use per housing unit by type/commercial sq ft.						
	Large lot single family detached (> 2000 sq ft home)	9,810 kWh	555 thm				
	Small lot single family detached (< 2000 sq ft home)	6,690 kWh	400 thm				
	Townhome	4,975 kWh	310 thm				
	Multifamily	4,100 kWh	200 thm				
	Average per commercial square foot	18.7 kWh	0.2 thm				
Energy use of existing buildings	Statewide average energy use per housing unit by type/commercial sq ft.						
	Average per housing unit	7,000 kWh	400 thm				
	Average per commercial square foot	18.7 kWh	0.2 thm				
Energy efficiency assumptions	Energy use reductions from baseline factors	*Refer to Appendix A for average residential and commercial*					
Electricity price	Price per kilowatt-hour (same as for transportation electricity)	$0.15		$0.17	$0.18	$0.19	$0.25
Natural gas price	Price per therm	$1.08		$1.32	$1.60	$1.75	$2.31
Water use of new residential buildings	Estimated statewide average use per housing unit, by type						
	Large lot single family detached (> 5500 sq ft lot)	160,000 gal					
	Small lot single family detached (< 5500 sq ft lot)	91,500 gal					
	Townhome	59,500 gal					
	Multifamily	56,000 gal					
Water price	Price per acre-foot	$1,822		$1,925	$2,147	$2,268	$2,672
Water efficiency assumptions	Water use reductions from baseline factors (not linked to E3)						
	Baseline			0%	0%	0%	0%
	Reference			-20%	-30%	-35%	-50%
	Straight Line			-30%	-40%	-45%	-65%
	Early Deployment			-30%	-40%	-45%	-65%
ENERGY EMISSIONS							
Building energy emissions, electricity	Pounds of CO_2e per kilowatt-hour (same as for transportation electricity)	*Refer to transportation electricity emissions*					
Building energy emissions, natural gas	Pounds of CO_2e per therm						
	Baseline	10.5		10.5	10.5	10.5	10.5
	Reference	10.5		10.5	10.5	10.5	10.5
	Straight Line	10.5		10.5	10.2	10.0	7.5
	Early Deployment	10.5		10.5	10.3	9.5	6.8