RAPID FIRE MODEL

Technical Summary
Model Version 2.0

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INTRODUCTION and RAPID FIRE MODEL OVERVIEW

This technical summary provides an overview of the key features and functionality of the *Rapid Fire* model developed by Calthorpe Associates. The Rapid Fire model is designed to produce and evaluate statewide, regional, and/or county-level scenarios across a range of metrics. This document is intended to impart a fundamental understanding of how Rapid Fire scenarios are formulated and analyzed.

The Rapid Fire Modeling Framework

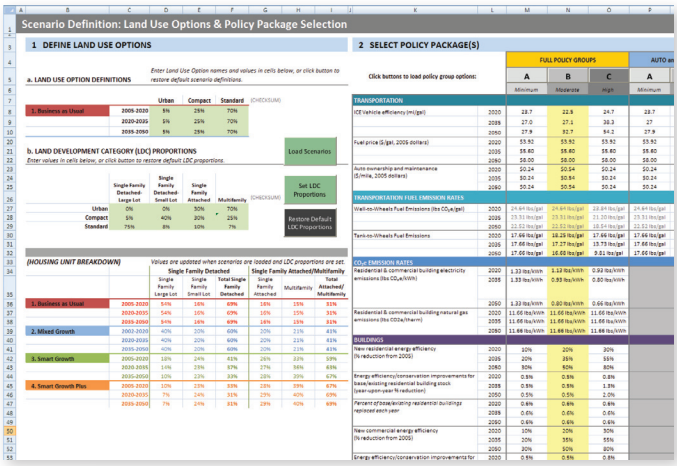
The Rapid Fire model emerged out of the near-term need for a comprehensive modeling tool that could inform state, regional, and local agencies and policy makers in evaluating climate, land use, and infrastructure investment policies. Results are calculated using empirical data and the latest research on the role of land use and transportation systems on automobile travel; emissions; public health; infrastrucutre cost; city revenues; and land, energy, and water consumption. The model constitutes a single framework into which these research-based assumptions can be loaded to test the impacts of varying land use patterns. The transparency of the model's structure of input assumptions makes it readily adaptable to different study areas, as well as responsive to data emerging from ongoing technical analyses by state, regional, and local agencies.

The model allows users to create scenarios at the national, statewide, or regional scales. Results are produced for a range of metrics, including:

- GHG (CO_2e) emissions from cars and buildings
- Air pollution
- Fuel use and cost
- Building energy use and cost
- Residential water use and cost
- Land consumption
- Fiscal impacts (local capital infrastructure and O&M costs; city revenues)
- City revenues
- Public health impacts

The Rapid Fire model is not meant to replace more complex travel models or map-based models; rather, it is designed to fill a timely need for defensible comparative analysis that can inform land use and climate policy development and provide a credible and flexible sounding board for state and regional entities as they review and analyze plans and policies. More information about model results and the Vision California process can be found at *www.visioncallifornia.org* and at *www.calthorpe.com/vision-california*.

This document starts with an overview of the operational flow of the model, continues with an explanation of how study areas are set and how scenarios are composed, and finally describes how assumptions are applied to calculate results in each metrics category.

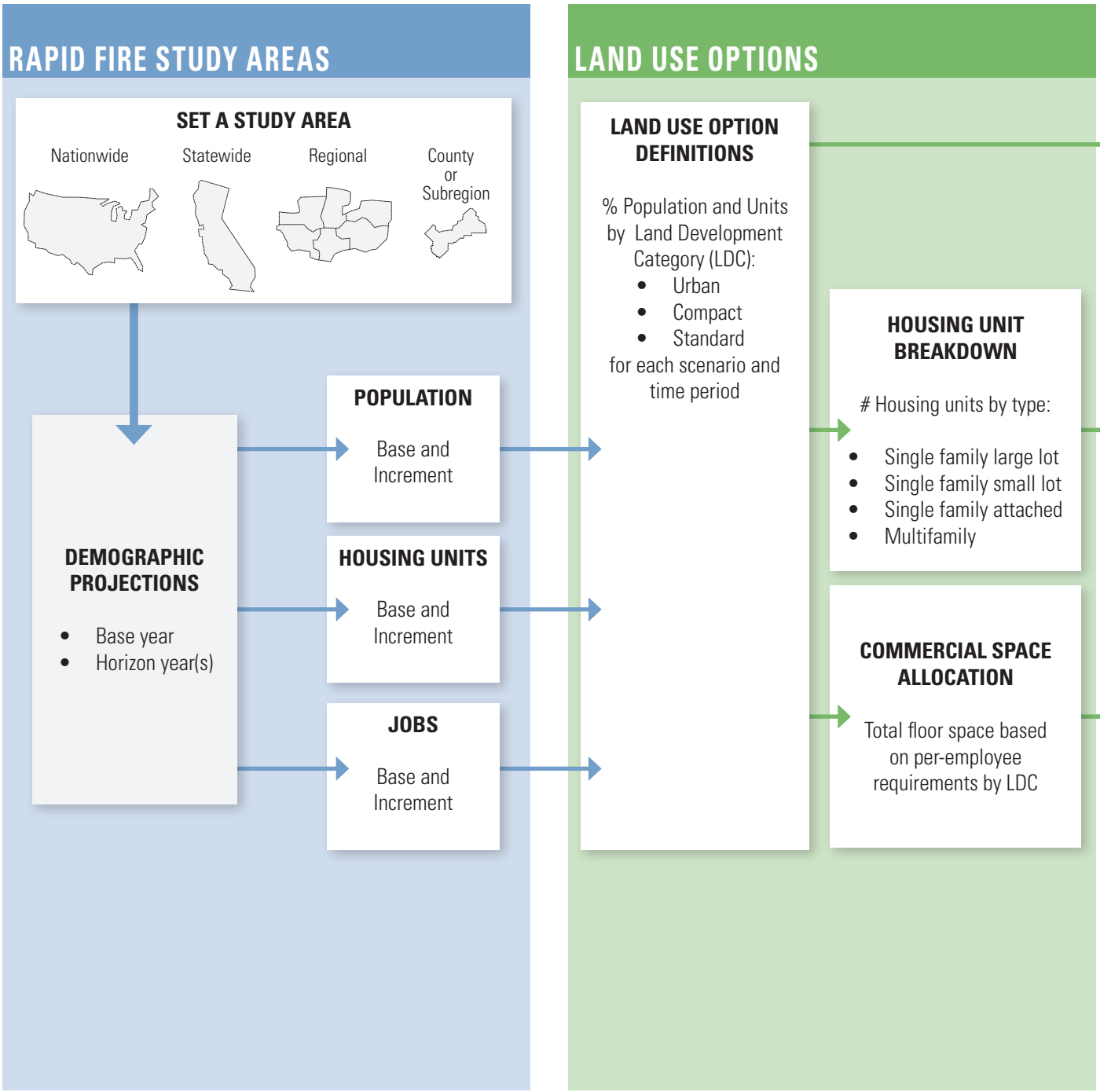


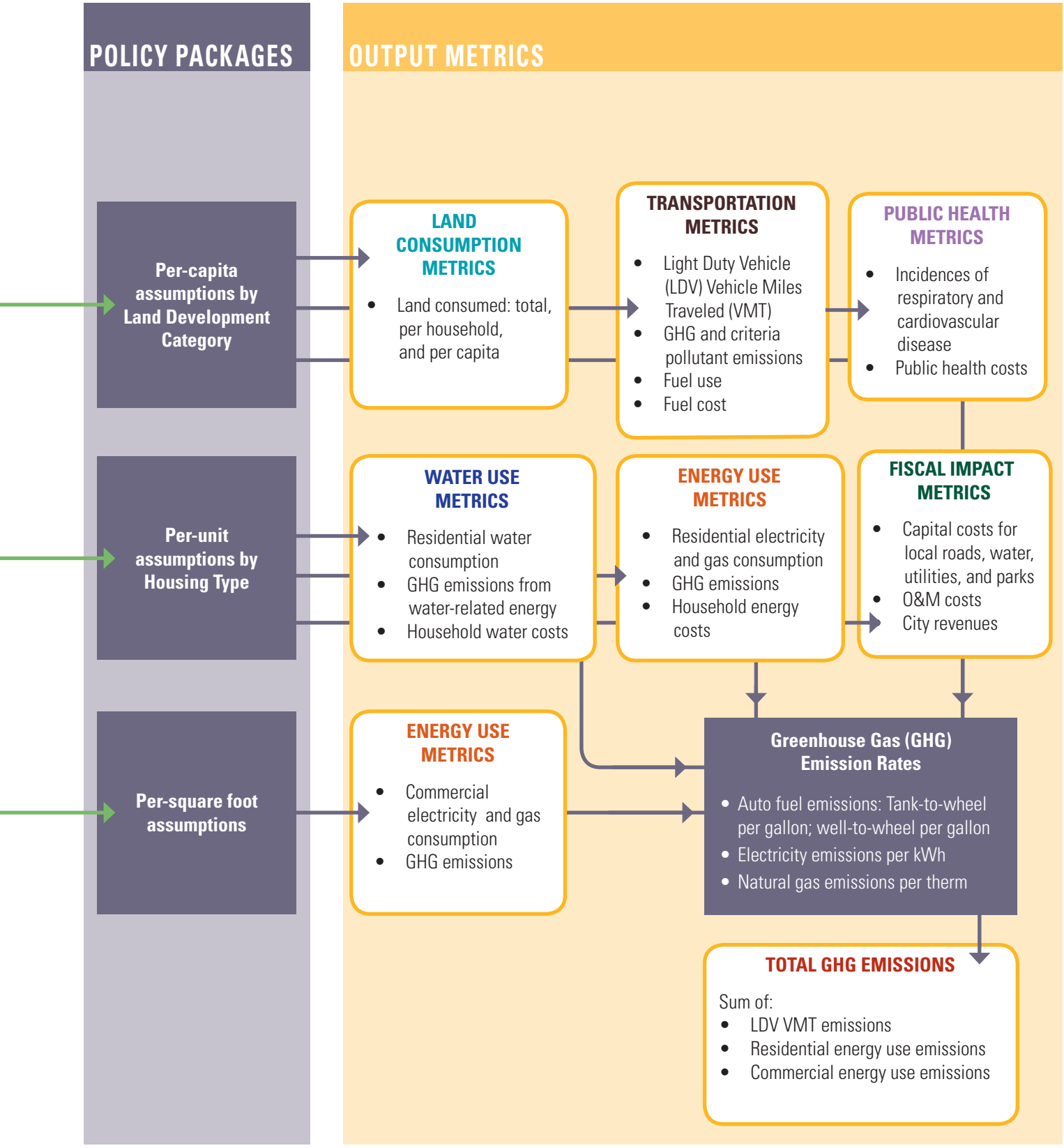
Technical Requirements. *The Rapid Fire model is a user-friendly, spreadsheet-based tool that allows for efficient testing of different combinations of compact, urban, and more sprawling growth. The model, which runs in Microsoft Excel, is designed to be flexible and transparent. All assumptions are clear and can be easily modified or customized.*

RAPID FIRE OPERATIONAL FLOW

From Input Assumptions to Output Metrics

The Rapid Fire model uses a full range of inputs, from demographic projections to travel behavior projections to technical factors for fuel and energy emissions, to calculate output metrics that demonstrate the relative effects of different land use scenarios and policy options. The following chart gives an overview of the operational flow of the model, starting from the selection of a study area, through the application of land use options and policy packages, to the final stage of metrics output. The chart generally categorizes the input assumptions by type; all assumptions are discussed in greater detail in the later sections of this paper.




POLICY PACKAGES
OUTPUT METRICS
Per-capita assumptions by Land Development Category
Per-unit assumptions by Housing Type
Per-square foot assumptions
LAND CONSUMPTION METRICS
• Land consumed: total, per household, and per capita
TRANSPORTATION METRICS
• Light Duty Vehicle (LDV) Vehicle Miles Traveled (VMT)
• GHG and criteria pollutant emissions
• Fuel use
• Fuel cost
PUBLIC HEALTH METRICS
• Incidences of respiratory and cardiovascular disease
• Public health costs
WATER USE METRICS
• Residential water consumption
• GHG emissions from water-related energy
• Household water costs
ENERGY USE METRICS
• Residential electricity and gas consumption
• GHG emissions
• Household energy costs
FISCAL IMPACT METRICS
• Capital costs for local roads, water, utilities, and parks
• O&M costs
City revenues
ENERGY USE METRICS
• Commercial electricity and gas consumption
• GHG emissions
Greenhouse Gas (GHG) Emission Rates
• Auto fuel emissions: Tank-to-wheel per gallon; well-to-wheel per gallon
• Electricity emissions per kWh
• Natural gas emissions per therm
TOTAL GHG EMISSIONS
Sum of:
• LDV VMT emissions
• Residential energy use emissions
• Commercial energy use emissions

Study areas can range in size, from the local to the national scale, so long as data are available. Study areas are defined by baseline demographic and performance data for an initial base year, and demographic projections for three horizon years. By default, the model uses a base year of 2005 and horizon years of 2020, 2035, and 2050, though these can be modified.

At a minimum, the following key assumptions (as listed in the table) are required to define a study area. These inputs are all geographically dependent—they vary according to study area rather than according to policy or other methodological assumptions.

Demographics	***Transportation***	***Building Energy***	***Water***
• *Baseline and projected population* • *Baseline and projected households* • *Baseline and projected jobs*	• *Average per-capita vehicle miles traveled (VMT)* • *Average LDV fuel economy* • *Baseline GHG emissions per gallon of fuel* • *Baseline auto ownership and maintenance costs per mile*	• *Baseline average energy use per existing residential unit and commercial square foot (can be derived from total residential and commercial energy use)* • *Baseline energy use by residential building type and commercial square foot* • *GHG emissions per kilowatt-hour (kWh) of electricity* • *GHG emissions per therm of natural gas* • *Baseline energy costs per kWh and therm*	• *Baseline residential water use per existing unit (can be derived from total water use)* • *Baseline per-capita water use*

Study Area Selection Sheet. *Input data are entered, stored, and loaded from the Study Area Selection sheet.*

Study Area Selection

	CALIFORNIA				UNITED STATES			
		Load Inputs				Load Inputs		
	2005 Baseline	2020	2035	2050	2005 Baseline	2020	2035	2050
Demographic inputs								
Population	36,676,931	44,135,923	51,753,503	59,507,876	296,410,404	341,387,000	389,531,000	439,010,000
Households	12,184,688	14,667,307	17,198,792	19,775,735	111,090,617	127,744,591	145,759,734	164,274,424
Non-farm Jobs	14,801,300	17,747,442	20,810,538	23,928,639	136,458,810	169,900,306	193,860,446	218,484,984
Transportation								
Baseline per-capita LDV VMT	8,100 mi				9,276 mi			
Baseline LDV fuel economy	18.7 MPG				18.9 MPG			
Baseline fuel emissions (WtW)	26.5 lbs/gal				25.0 lbs/gal			
Baseline fuel emissions (TtW)	19.62 lbs/gal				19.6 lbs/gal			
Baseline LDV fuel cost, per gallon	$2.75				$1.87			
Baseline LDV auto ownership cost, per mile	$0.24				$0.24			
Baseline LDV tire and maintenance cost, per mile	$0.065				$0.065			
Building Energy Emissions								
Electricity generation (lbs/kWh)	0.81 lbs/kWh				1.33 lbs/kWh			
Gas combustion (lbs/therm)	11.66 lbs/therm				11.66 lbs/therm			
Residential Building Energy Use								
	Electricity	*Natural Gas*			*Electricity*	*Natural Gas*		
Baseline average annual energy use per unit for base/existing population	7,064 kWh	401 thm			11,480 kWh	670 thm		
Annual energy use by building type:								
Single Family Detached- Large Lot	9,355 kWh	675 thm			14,800 kWh	743 thm		
Single Family Detached- Small Lot	6,380 kWh	488 thm			11,000 kWh	700 thm		
Single Family Attached	4,745 kWh	378 thm			9,240 kWh	680 thm		

The Rapid Fire model analyzes up to four scenarios at a time. Each scenario consists of two components: a *land use option* and a *policy package*. The land use options vary the patterns of new growth, while the policy packages vary standards for automobile technology and fuel composition; building energy and water efficiency; and energy generation.

Land Use Options

The land use options all accommodate the same amount of projected population and job growth, but differ in how that growth is allocated. The user defines a land use option by varying the proportions of growth in each of three *Land Development Categories (LDCs)* – Urban, Compact, and Standard. The LDCs represent distinct forms of land use, ranging from dense, walkable, mixed-use urban areas that are well served by transit, to lower-intensity, less walkable places where land uses are segregated and most trips are made via automobile. Each LDC is associated with different travel behaviors and a different mix of housing types and commercial space profiles, as described generally on the next page.

The Rapid Fire model is loaded with four default land use options – ***Business as Usual, Mixed Growth, Smart Growth, and Smart Growth Plus*** – all which can be modified by the user. The figure at right shows the area of the Scenario Definition sheet in which land use options and the housing unit mixes of each LDC are defined. The definition and resulting housing type mix of an example land use option is outlined in the diagram on page 9.

Land Use Option Section of Scenario Definition Sheet. *Proportions for land use options and LDCs are set in the Land Use Option section of the Scenario Definition sheet.*

1 DEFINE LAND USE OPTIONS

a. LAND USE OPTION DEFINITIONS

Enter Land Use Option names and values in cells below, or click button to restore default scenario definitions.

		Urban	Compact	Standard	(CHECKSUM)
1. Business as Usual	2005-2020	5%	25%	70%	
	2020-2035	5%	25%	70%	
	2035-2050	5%	25%	70%	
2. Mixed Growth	2005-2020	10%	40%	50%	
	2020-2035	10%	40%	50%	
	2035-2050	10%	40%	50%	
3. Smart Growth	2005-2020	25%	55%	20%	
	2020-2035	30%	55%	15%	
	2035-2050	35%	55%	10%	
4. Smart Growth Plus	2005-2020	35%	55%	10%	
	2020-2035	35%	60%	5%	
	2035-2050	35%	60%	5%	

Load Scenarios

Restore Default Scenarios

b. LAND DEVELOPMENT CATEGORY (LDC) PROPORTIONS

Enter values in cells below, or click button to restore default LDC proportions.

	Single Family Detached-Large Lot	Single Family Detached-Small Lot	Single Family Attached	Multifamily	(CHECKSUM)
Urban	0%	0%	30%	70%	
Compact	5%	40%	30%	25%	
Standard	75%	8%	10%	7%	

Set LDC Proportions

Restore Default LDC Proportions

(HOUSING UNIT BREAKDOWN) *Values are updated when scenarios are loaded and LDC proportions are set.*

		Single Family Detached			Single Family Attached/Multifamily		
		Single Family Large Lot	Single Family Small Lot	Total Single Family Detached	Single Family Attached	Multifamily	Total Attached/ Multifamily
1. Business as Usual	2005-2020	54%	16%	69%	16%	15%	31%
	2020-2035	54%	16%	69%	16%	15%	31%
	2035-2050	54%	16%	69%	16%	15%	31%
2. Mixed Growth	2002-2020	40%	20%	60%	20%	21%	41%
	2020-2035	40%	20%	60%	20%	21%	41%
	2035-2050	40%	20%	60%	20%	21%	41%
3. Smart Growth	2005-2020	18%	24%	41%	26%	33%	59%
	2020-2035	14%	23%	37%	27%	36%	63%
	2035-2050	10%	23%	33%	28%	39%	67%
4. Smart Growth Plus	2005-2020	10%	23%	33%	28%	39%	67%
	2020-2035	7%	24%	31%	29%	40%	69%
	2035-2050	7%	24%	31%	29%	40%	69%

LAND USE OPTIONS

Land Development Categories

The Urban, Compact, and Standard LDCs represent distinct forms of land use. Their general land use characteristics and transportation infrastructure are described below. These characteristics are all determined by model inputs that can be entered or adjusted by the user.

	Land Use Characteristics	Transportation Infrastructure
URBAN	Most intense and most mixed LDC, often found within and directly adjacent to moderate and high density urban centers. Virtually all 'Urban' growth would be considered infill or redevelopment. The majority of housing in Urban areas is multifamily and attached single family (townhome). These housing types tend to consume less water and energy than the larger single family types found in greater proportion in less urban locations.	Supported by high levels of regional and local transit service. Well-connected street networks and the mix and intensity of uses result in a highly walkable environment and relatively low dependence on the automobile for many trips. **Per-capita VMT range: ~ 1,500 to 4,000 per year.**
COMPACT	Less intense than Urban LDC, but highly walkable with rich mix of retail, commercial, residential, and civic uses. The Compact form is most likely to occur as new growth on the urban edge or large-scale redevelopment. Rich mix of housing, from multifamily and attached single family (townhome) to small- and medium-lot single family homes. Housing types in Compact areas tend to consume less energy and water than the larger types found in the Standard LDC.	Well served by regional and local transit service, but may not benefit from as much service as Urban growth, 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. **Per-capita VMT range: ~ 4,000 to 7,500 per year.**
STANDARD	Represents the majority of separate-use auto-oriented development that has dominated the American suburban landscape over the past decades. Densities tend to be lower than Compact LDC, and are generally not highly mixed or organized to facilitate walking, biking, or transit service. Can contain a wide variety of housing types, though medium- and larger-lot single family homes comprise the majority of this development form; these larger single family tend to consume more energy and water than those in the Urban or Compact LDCs.	Not well served by regional transit service (typically), with most trips made via automobile. **Per-capita VMT range: ~ 9,500 to 18,000 per year.**

Housing Unit Mix

The housing mix assumptions for the three LDCs lead to an overall mix of housing units for each land use option and time period. The default housing mix assumptions for the LDCs are intended to reflect existing land use patterns and policies, and thus remain constant for each LDC over time. Housing unit mix assumptions can be changed to represent shifts in housing demand over time, or to represent different market conditions among land use options.

Urban areas are comprised of multifamily and attached single family units. Compact areas contain the widest range of housing types, from multifamily and attached single family to small-lot single family units, with a small proportion of large-lot single family units. Standard development is dominated by large-lot single family units, with small proportions of other housing types. The LDC and housing unit mix assumptions for the default "Smart Growth" land use option are shown below.

Assumptions by Land Development Category

The housing unit mix assumptions are applied to the housing growth projected for each LDC (determined by the proportion of population growth allocated to the LDC within a scenario/time period) to produce housing counts by type.

1 DEFINE LAND USE OPTIONS

a. LAND USE OPTION DEFINITIONS

Enter Land Use Option names and values in cells below, or click button to restore default scenario definitions.

		Urban	Compact	Standard	(CHECKSUM)
1. Business as Usual	2005-2020	5%	25%	70%	
	2020-2035	5%	25%	70%	
	2035-2050	5%	25%	70%	
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	2020-2035	10%	40%	50%	
	2035-2050	10%	40%	50%	
3. Smart Growth	2005-2020	25%	55%	20%	*
	2020-2035	30%	55%	15%	
	2035-2050	35%	55%	10%	
4. Smart Growth Plus	2005-2020	35%	55%	10%	
	2020-2035	35%	60%	5%	
	2035-2050	35%	60%	5%	

Load Scenarios

Restore Default Scenarios

b. LAND DEVELOPMENT CATEGORY (LDC) PROPORTIONS

Enter values in cells below, or click button to restore default LDC proportions.

	Single Family Detached-Large Lot	Single Family Detached-Small Lot	Single Family Attached	Multifamily	(CHECKSUM)
Urban	0%	0%	30%	70%	
Compact	5%	40%	30%	25%	
Standard	75%	8%	10%	7%	

Set LDC Proportions

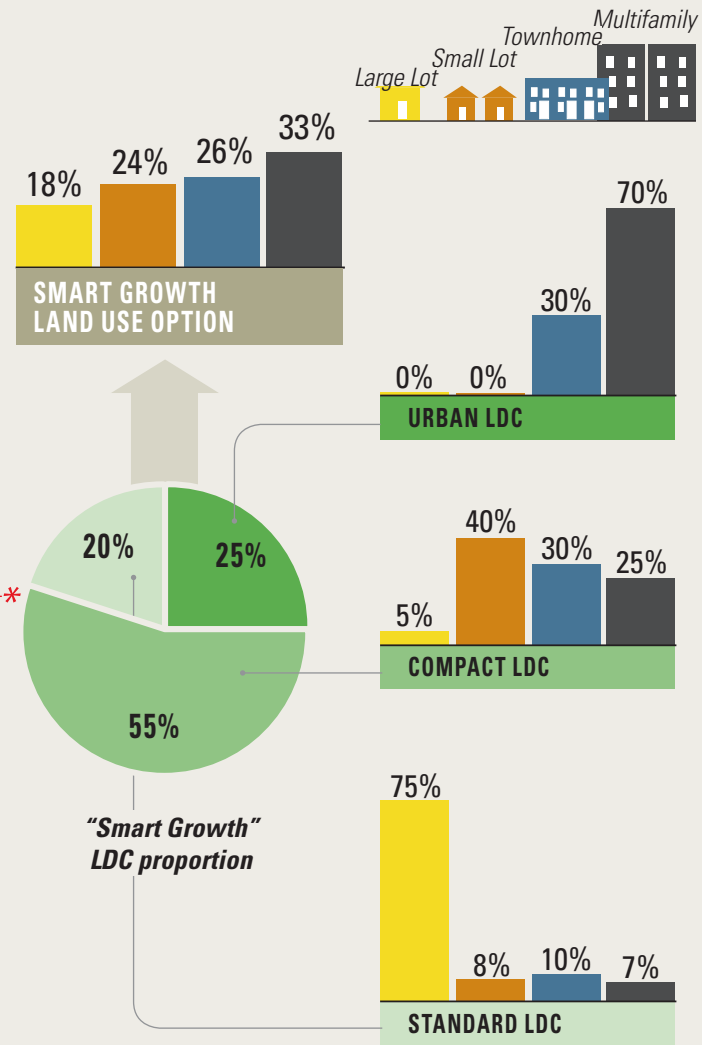
Restore Default LDC Proportions

(HOUSING UNIT BREAKDOWN)

Values are updated when scenarios are loaded and LDC proportions are set.

		Single Family Detached			Single Family Attached/Multifamily		
		Single Family Large Lot	Single Family Small Lot	Total Single Family Detached	Single Family Attached	Multifamily	Total Attached/ Multifamily
1. Business as Usual	2005-2020	54%	16%	69%	16%	15%	31%
	2020-2035	54%	16%	69%	16%	15%	31%
	2035-2050	54%	16%	69%	16%	15%	31%
2. Mixed Growth	2002-2020	40%	20%	60%	20%	21%	41%
	2020-2035	40%	20%	60%	20%	21%	41%
	2035-2050	40%	20%	60%	20%	21%	41%
3. Smart Growth	2005-2020	18%	24%	41%	26%	33%	59%
	2020-2035	14%	23%	37%	27%	36%	63%
	2035-2050	10%	23%	33%	28%	39%	67%
4. Smart Growth Plus	2005-2020	10%	23%	33%	28%	39%	67%
	2020-2035	7%	24%	31%	29%	40%	69%
	2035-2050	7%	24%	31%	29%	40%	69%

Default Housing Mix Assumptions for LDCs



POLICY PACKAGE ASSUMPTIONS

Rapid Fire policy packages vary standards for automobile technology and fuel composition, building energy and water efficiency, and energy generation. *Auto and Fuel Technology* assumptions include those that guide vehicle efficiency, fuel emissions, and costs; *Building Efficiency* assumptions include building energy and water use standards as well as utility costs; and *Utility Portfolio* assumptions drive the carbon intensity of the power generation sector.

Policy-based input assumptions are grouped to represent different levels of improvement in each of these categories. While users can enter any combination of input assumptions, the policy packages allow users to instantly activate and switch between sets of assumptions to compare results. The components of the policy package categories are outlined in the table below.

As with the land use options, the policy packages can reflect a range of futures, from a business-as-usual case that continues current trends, to a progressive case that represents significant policy action. Users can enter values to define up to three alternate policy packages in each category.

Policy Package Selection Section of Scenario Definition Sheet. *The policy packages are organized in sections on the 'Scenario Definition' sheet as shown below. Clicking on the buttons labeled A, B, and C at the top of each column loads input values to the 'Active Scenario' column located at the right of the 'Utility Portfolio' section (not shown). Users can select a 'Full Policy Group' of minimum, moderate, or high options, or they can select an option for each individual policy group. Once selected, the cells containing the active input values are highlighted in yellow (*). In this sample view, the 'moderate' level full policy group is selected.*

*

2 SELECT POLICY PACKAGE(S)

Click buttons to load policy group options:		FULL POLICY GROUPS			AUTO and FUEL TE	
		A	B	C	A	B
		Minimum	*Moderate*	*High*	*Minimum*	*Moderat*
TRANSPORTATION						
ICE Vehicle efficiency (mi/gal)	2020	23.7	22.5	24.7	23.7	22.5
	2035	27.0	27.1	38.3	27	27.1
	2050	27.9	32.7	54.2	27.9	32.7
Fuel price ($/gal, 2005 dollars)	2020	$3.92	$3.92	$3.92	$3.92	$3.92
	2035	$5.60	$5.60	$5.60	$5.60	$5.60
	2050	$8.00	$8.00	$8.00	$8.00	$8.00
Auto ownership and maintenance ($/mile, 2005 dollars)	2020	$0.24	$0.54	$0.24	$0.24	$0.54
	2035	$0.24	$0.54	$0.24	$0.24	$0.54
	2050	$0.24	$0.54	$0.24	$0.24	$0.54
TRANSPORTATION FUEL EMISSION RATES						
Well-to-Wheels Fuel Emissions (lbs CO_2e/gal)	2020	24.64 lbs/gal	24.64 lbs/gal	23.84 lbs/gal	24.64 lbs/gal	24.64 lbs/
	2035	23.31 lbs/gal	23.31 lbs/gal	21.20 lbs/gal	23.31 lbs/gal	23.31 lbs/
	2050	22.52 lbs/gal	22.52 lbs/gal	18.54 lbs/gal	22.52 lbs/gal	22.52 lbs/
Tank-to-Wheels Fuel Emissions	2020	17.66 lbs/gal	18.25 lbs/gal	17.66 lbs/gal	17.66 lbs/gal	18.25 lbs/
	2035	17.66 lbs/gal	17.27 lbs/gal	13.73 lbs/gal	17.66 lbs/gal	17.27 lbs/
	2050	17.66 lbs/gal	16.68 lbs/gal	9.81 lbs/gal	17.66 lbs/gal	16.68 lbs/
CO_2e EMISSION RATES						
Residential & commercial building electricity	2020	1.33 lbs/kWh	1.13 lbs/kWh	0.93 lbs/kWh		

Auto and Fuel Technology

- *Internal combustion engine (ICE) vehicle fuel efficiency (miles per gallon)*
- *Fuel price ($ per gallon)*
- *Well-to-wheels GHG emissions from fuel (lbs CO2e per gallon)*
- *Tank-to-wheels GHG emissions from fuel (lbs CO2e per gallon)*
- *Percent alternative/electric vehicles*
- *Battery electric vehicle efficiency (miles/kWh)*
- *Plug-in hybrid electric vehicle efficiency (miles/kWh)*

Building Efficiency

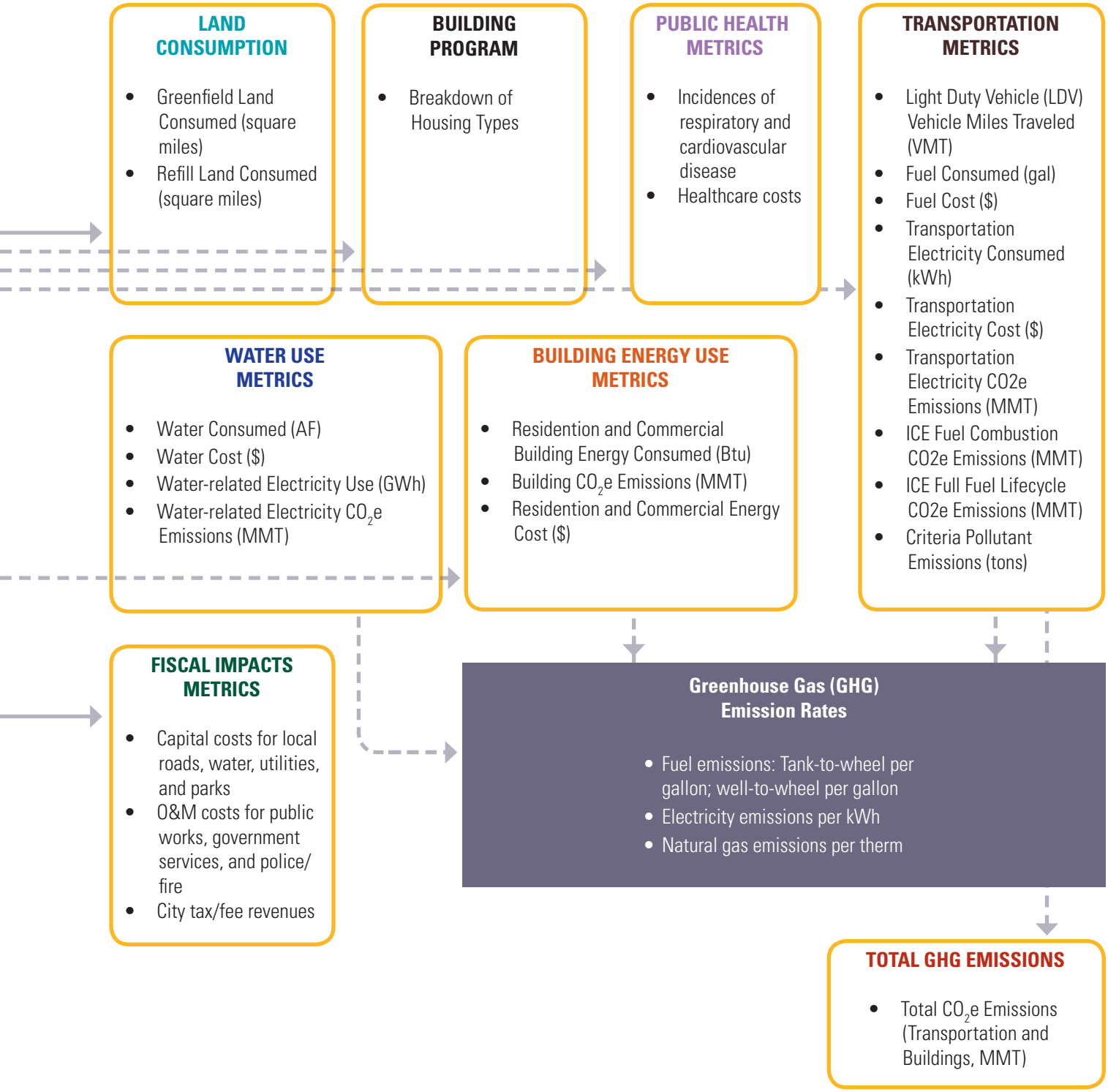
- *New residential energy efficiency (% reduction from 2005 baseline use)*
- *New commercial energy efficiency (% reduction from 2005 baseline use)*
- *New residential water efficiency (% reduction from 2005)*
- *Energy efficiency/conservation improvements for base/existing residential building stock (year-upon-year % reduction)*
- *Energy efficiency/conservation improvements for base/existing commercial space (year-upon-year % reduction)*
- *Percent of base/existing residential buildings replaced each year*
- *Percent of base/existing commercial floorspace replaced each year*
- *Electricity price ($ per kWh)*
- *Natural gas price ($ per kWh)*
- *Water price ($ per acre foot)*

Utility Portfolio

- *Residential & commercial building electricity emissions (lbs CO_2e per kWh)*
- *Residential & commercial building natural gas emissions (lbs CO_2e per therm)*

OUTPUT METRICS

The following sections describe how the model uses input assumptions to calculate results in each of the metrics categories. The categories of output metrics are summarized below.



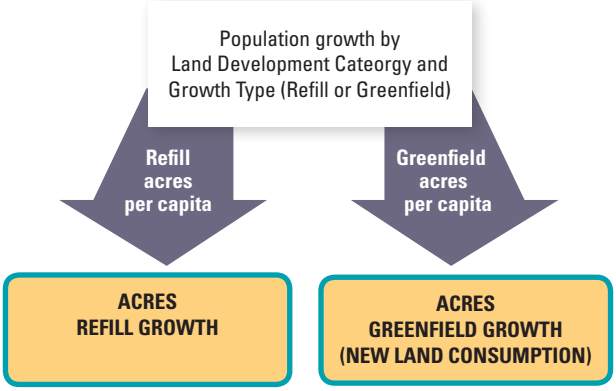
LAND CONSUMPTION

Land consumption includes all land that will be developed to accommodate population and job growth, including residential and employment areas, transportation alignments, open space, and public lands. The Rapid Fire model estimates land consumption using per-capita rates of land consumption, which vary by Land Development Category and the distribution of growth into greenfield or refill development. Default rates are based on studies of existing and planned development, and can be adjusted by the user.

Land consumption includes both refill and greenfield growth. Refill growth includes all development that may occur within the bounds of already-developed, urbanized areas, including infill, redevelopment, and greyfield and brownfield development. Greenfield growth refers to development that occurs on land that has not previously been developed or otherwise impacted, including agricultural land, forest land, desert land and other virgin sites. Only greenfield growth is counted towards the "new land consumption" of a scenario. The default land consumption characteristics for the three LDCs are as follows:

Urban: Comprised entirely of infill, redevelopment, greyfield, and brownfield growth, the Urban LDC consumes no greenfield acreage per capita.

Compact: Representing a combination of smart mixed-use growth in and around the urban edge (greenfield growth) as well as larger-scale greyfield growth within urban areas, the Compact LDC consumes a moderate acreage per capita. The land consumption rate for Compact growth is determined in part by the proportion of growth allocated to refill versus greenfield sites.



Standard: Generally consisting of lower-density, auto-oriented residential and commercial development, the Standard LDC consumes the highest acreage per capita since most, if not all, growth occurs on greenfield land. The new land consumption of a scenario is largely dictated by its proportion of Standard development.

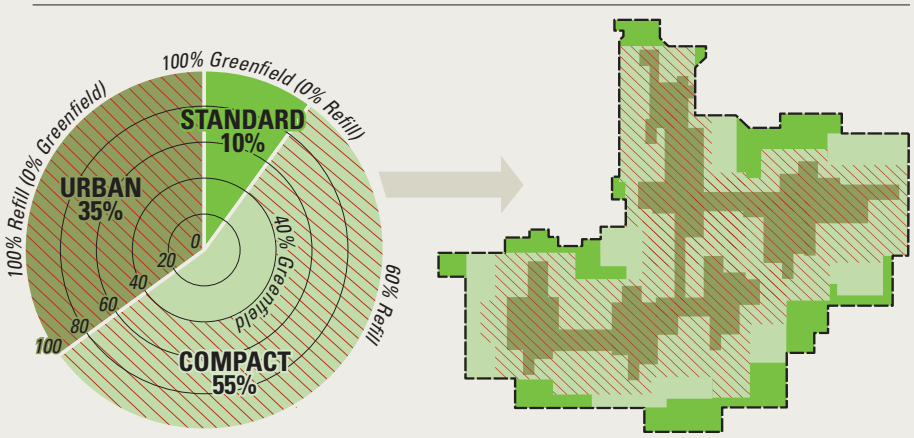
The specific allocation of growth to either refill or greenfield land in each LDC and time period can vary by land use option. By setting assumptions for the proportion of refill growth and greenfield land consumption, as well as the intensity of greenfield growth in terms of acres consumed per capita, users can model a range of land-use policy options, from business-as-usual growth, to the application of urban growth boundaries, to a restriction of growth to refill parcels and sites only.

A land development profile resulting from the LDC mix of the Rapid Fire default "Smart Growth" land use option is illustrated in the figure below.

Refill Growth and Greenfield Land Consumption

The LDCs differ significantly in the population allocated to either refill growth or greenfield land. The assumed proportions for Urban and Standard are straightforward: all Urban development takes place as refill growth, while virtually all Standard development takes place on greenfield land. These characteristics are elemental to the Urban and Standard LDC definitions. The land consumption characteristics of Compact development, however, can vary significantly over time, by scenario, and by geographic area. The incremental land consumption rate of the Compact LDC is largely dependent on the assumed proportion of refill growth vs. development on new land.

Land Development Profile of "Smart Growth" Land Use Option (Illustrative Only)



FISCAL IMPACTS

The Rapid Fire model's fiscal impacts analysis module allows users to compare the cost and budget implications of varying scenarios and forms of development. The Rapid Fire model incorporates cost and revenue data from a number of local, regional, state, and utility sources to derive infrastructure cost factors on a per-housing unit basis according to land use option and development condition (refill or greenfield). Estimates are made for capital infrastructure costs, operations and maintenance costs, and city revenues from taxes and fees.

Capital costs for the following infrastructure elements are included:

- City costs for streets and transportation
- Water supply
- Sewage and wastewater
- Local parks

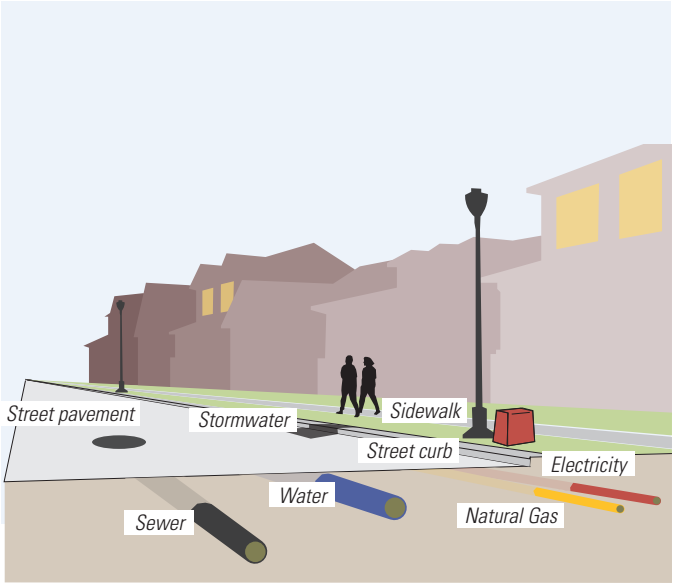
Operations and maintenance (O&M) costs estimates include the following categories of general fund spending:

- Public works functions
- General government services
- Public safety (police and fire)
- Community services

Jurisdictional revenues are estimated from the following tax and fee types:

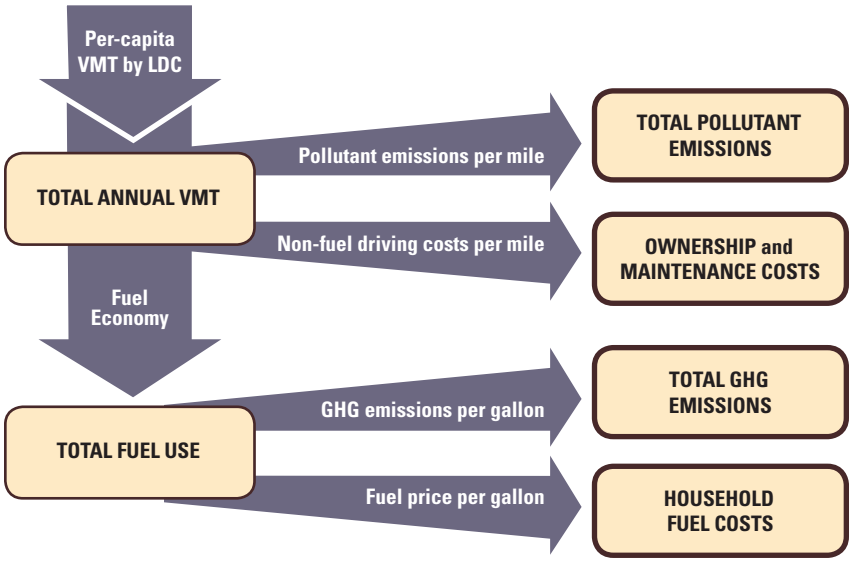
- Property tax
- Property transfer tax
- Vehicle license fees

Calthorpe Associates worked with the firm Strategic Economics to develop the assumptions that drive infrastructure cost estimates and jurisdictional revenues. Assumptions are sensitive to development type and condition, including cost and revenue variations for both refill (infill and redevelopment) and greenfield locations. Note that the current version of the model estimates the impacts of variations in residential development unit types and patterns; future versions will incorporate the fiscal impacts due to commercial development variations.



All transportation metrics in the Rapid Fire model are calculated on the basis of light-duty/passenger vehicle miles traveled (VMT). From VMT, the model estimates fuel use, greenhouse gas (GHG) and criteria pollutant emissions, and fuel and other driving costs.

Criteria pollutant emissions and non-fuel driving costs are calculated by applying per-mile assumptions to VMT. Fuel use is calculated according to vehicle fuel economy assumptions. In turn, GHG emissions are calculated based on per-gallon emission rates. All metrics are calculated on a total annual basis for every year leading up to the final horizon year. Per-capita and per-household averages are derived from annual and cumulative totals.



Vehicle Miles Traveled

The Rapid Fire model calculates VMT by applying assumptions about per-capita annual VMT to population growth. These assumptions, which differ by Land Development Category, are based on research and empirical evidence that per-capita VMT of both incremental (new) population and base year (existing) population vary based on the form of new growth. Moreover, this variation is expected to change over time as areas become either more urban or compact, or more sprawling (determined on the proportions of LDCs in a scenario).

Variations in VMT across the scenarios is a result of year-by-year variation in per capita VMT by form of new growth (Urban, Compact, or Standard), and also the impact of new growth on the travel behavior of those already living in the study area in the base year (2005). For example, if one is living in an area 20 years from now that has seen 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) because daily destinations and services are closer.

It is an a priori assumption of the Rapid Fire model that requisite transportation investments go hand in hand with growth 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 dominated by Standard development would see large budget outlays to highway and road expansion.

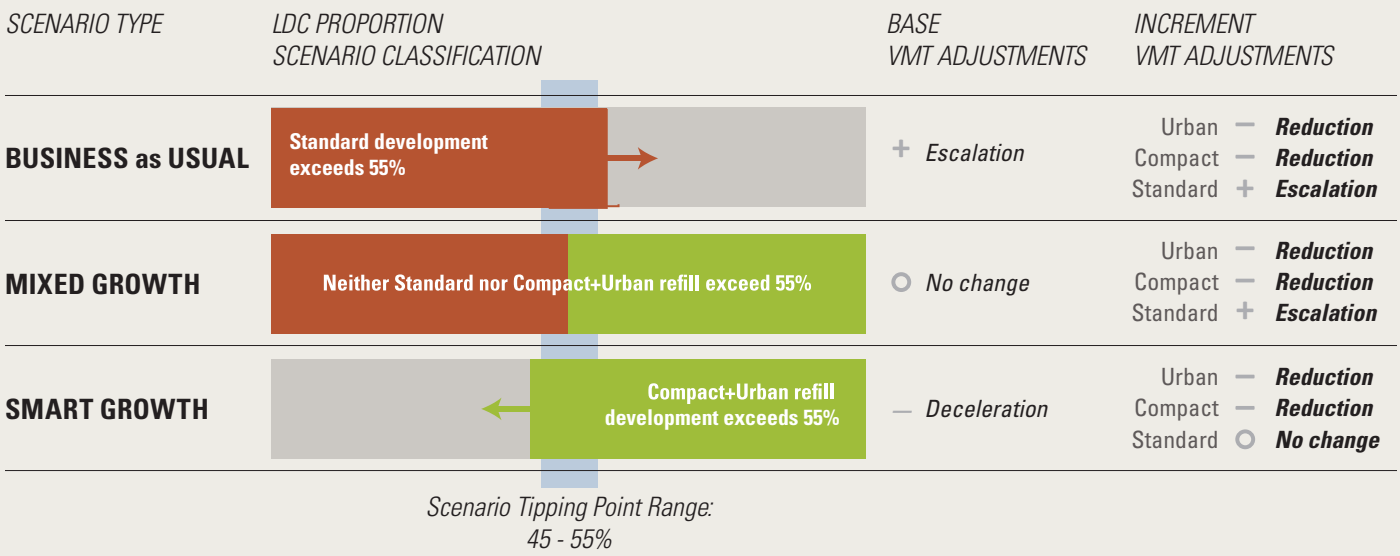
Base and Increment VMT Rates

The Rapid Fire VMT assumptions are applied as adjustment factors to both incremental growth and the base year (existing) population. The user defines specific percentage increases or reductions from a baseline average VMT rate (which is specific to a study area).

For the growth increment, adjustment factors for each LDC within a land use option are applied to the baseline per-capita VMT rate. For the base population, adjustment factors are applied to total base year VMT. Varying factors are applied depending on the mix of LDCs in a specific scenario, and the amount of growth that occurs on refill or greenfield land (see the Land Consumption section for more information about refill and greenfield growth). The figure on the next page summarizes the relationship between scenario mix and the application of VMT adjustment factors.

All VMT assumptions can be readily changed in the Rapid Fire model to test alternative hypotheses, integrate new empirical data, or calibrate to regional travel or other model outputs.

Base and Increment VMT Adjustment Factors by Scenario Type. *If a scenario is more oriented towards Standard development, then VMT is calculated to increase at a greater rate than if a scenario is more focused towards Urban and Compact growth. Overall scenario orientation is determined using a "tipping point" range. If Standard development falls below the range, adjustment factors reflective of progressively decreasing VMT are applied; conversely, if Standard development surpasses the range, factors reflective of increasing VMT are applied. If Standard development falls within the tipping point range, then driving behavior does not change further beyond the default rates.*



Detailed VMT Assumptions Sheet. *Inputs are entered, stored, and loaded from the Study Area Selection sheet.*

Detailed VMT Assumptions

Baseline per-capita LDV VMT

1990	7,377
2005	9,276 mi

Load VMT Assumptions

Restore Defaults

BASE VMT ADJUSTMENT ASSUMPTIONS

VMT Escalation/Deceleration Rates for the Base (Existing Environment)

ESCALATION RATE: Standard Impact on Base VMT in Trend Scenario		
2005-2020	0.50%	Annual Rate
2020-2035	0.00%	Annual Rate
2035-2050	0.00%	Annual Rate
DECELERATION RATE: Compact+Urban Growth Impact on Base VMT in Smart Scenarios		
2005-2020	0.50%	Maximum Annual Rate
2020-2035	0.563%	Maximum Annual Rate
2035-2050	0.63%	Maximum Annual Rate
Intermediate Range Definition:		
These percentages are used to determine when to apply escalation/deceleration rates, as well as the appropriate VMT by LDC.		
Standard-Low:	45%	or less of scenario is Standard Growth
Standard-High:	55%	or more of scenario is Standard Growth

INCREMENT VMT ASSUMPTIONS

Adjustment factors relative to baseline average VMT (Applied to incremental population only)

		2006 Starting Point Adjustment Rate				2020 Adjustment Rate				2035 Adjustment Rate				
		for Refill		for Greenfield		for Refill		for Greenfield		for Refill		for Greenfield		for Refill
Standard	Standard Adjustment Factor for Trend Scenarios	20%	11,131	50%	13,914	20%	11,131	60%	14,842	35%	12,523	60%	14,842	55%
	Standard Adjustment Factor for Conservative Scenarios	20%	11,131	50%	13,914	15%	10,667	40%	12,986	15%	10,667	40%	12,986	15%
	Standard VMT per Capita in Smart Growth Scenarios	20%	11,131	50%	13,914	10%	10,204	25%	11,595	10%	10,204	20%	11,131	10%
	Standard VMT per Capita in Ultra Smart Growth Scenarios	20%	11,131	50%	13,914	10%	10,204	25%	11,595	10%	10,204	20%	11,131	10%
Compact	Compact Adjustment Factor for Trend Scenarios	-20%	7,421	-10%	8,348	-20%	7,421	-10%	8,348	-20%	7,421	-10%	8,348	-20%
	Compact Adjustment Factor for Conservative Scenarios	-20%	7,421	-10%	8,348	-25%	6,957	-15%	7,885	-30%	6,493	-20%	7,421	-35%
	Standard VMT per Capita in Smart Growth Scenarios	-20%	7,421	-10%	8,348	-35%	6,029	-20%	7,421	-40%	5,566	-25%	6,957	-45%
	Standard VMT per Capita in Ultra Smart Growth Scenarios	-20%	7,421	-10%	8,348	-35%	6,029	-20%	7,421	-40%	5,566	-25%	6,957	-45%
Urban	Urban Adjustment Factor for Trend Scenarios	-40%	5,566	-35%	6,029	-40%	5,566	-35%	6,029	-40%	5,566	-35%	6,029	-40%
	Urban Adjustment Factor for Conservative Scenarios	-40%	5,566	-35%	6,029	-45%	5,102	-40%	5,566	-50%	4,638	-45%	5,102	-55%
	Standard VMT per Capita in Smart Growth Scenarios	-40%	5,566	-35%	6,029	-50%	4,638	-45%	5,102	-60%	3,710	-50%	4,638	-70%
	Standard VMT per Capita in Ultra Smart Growth Scenarios	-40%	5,566	-35%	6,029	-50%	4,638	-45%	5,102	-60%	3,710	-50%	4,638	-70%

Resulting VMT per Capita, by Land Development Category and Scenario

		2006 Starting Values		2020		2035		2050	
		VMT	*% Change from 2005*	VMT	*% Change from 2005*	VMT	*% Change from 2005*	VMT	*% Change from 2005*
Standard	Standard VMT per Capita in Trend Scenario	13,914	*50%*	14,842	*60%*	14,842	*60%*	14,842	*60%*
	Standard VMT per Capita in Conservative Scenario	13,914	*50%*	12,986	*40%*	12,986	*40%*	12,986	*40%*
	Standard VMT per Capita in Smart Growth Scenario	13,914	*50%*	11,595	*25%*	11,131	*20%*	10,667	*15%*
	Standard VMT per Capita in Ultra Smart Growth Scenario	13,914	*50%*	11,595	*25%*	11,131	*20%*	10,667	*15%*
Compact	Compact VMT per Capita in Trend Scenario	8,209	*-12%*	8,209	*-12%*	8,209	*-12%*	8,209	*-12%*
	Compact VMT per Capita in Conservative Scenario	8,163	*-12%*	7,699	*-17%*	7,143	*-23%*	6,586	*-29%*
	Compact VMT per Capita in Smart Growth Scenario	7,977	*-14%*	6,864	*-26%*	6,261	*-33%*	5,658	*-39%*
	Compact VMT per Capita in Ultra Smart Growth Scenario	7,699	*-17%*	6,447	*-31%*	5,844	*-37%*	5,380	*-42%*
Urban	Urban VMT per Capita in Trend Scenario	5,566	*-40%*	5,566	*-40%*	5,566	*-40%*	5,566	*-40%*
	Urban VMT per Capita in Conservative Scenario	5,566	*-40%*	5,102	*-45%*	4,638	*-50%*	4,174	*-55%*
	Urban VMT per Capita in Smart Growth Scenario	5,566	*-40%*	4,638	*-50%*	3,710	*-60%*	2,783	*-70%*
	Urban VMT per Capita in Ultra Smart Growth Scenario	5,566	*-40%*	4,638	*-50%*	3,710	*-60%*	2,783	*-70%*

The Rapid Fire model calculates transportation fuel use, GHG and criteria pollutant emissions, and costs by applying policy-based assumptions to output VMT. Each metric is calculated on a total annual basis for all years in the model.

Fuel Use

LDV fuel consumption is determined by applying on-road average fuel economy assumptions (miles per gallon of gasoline equivalent[1], or MPG) to VMT in each year for each scenario. Fuel economy changes year upon year according to horizon-year projections. Policy-based projections significantly affect fuel consumption, and thus GHG emission and fuel cost results. Users can easily input and test alternate assumptions, such as compliance with California's Pavley Clean Car Standards or the federal CAFE standard, either in isolation or in combination with fuel carbon intensity assumptions.

Electric and other low-emission vehicles will play an important role in reducing GHG emissions. The Rapid Fire model can reflect their impacts in either of two ways: through the use of fuel economy and emission assumptions that implicitly capture the effects of their inclusion in the fleet[2], or through the use of separate assumptions for electric and conventional (internal combustion engine) vehicles.

GHG Emissions

Transportation GHG emissions are calculated by applying carbon intensity assumptions, expressed in pounds of carbon dioxide equivalent (CO_2e) per gallon, to fuel consumption. Carbon intensity changes year upon year according to horizon-year projections. Projections can represent a range of standards, from a trend future in which carbon intensity remains constant or sees limited improvement, to a more aggressive policy-based future in which the carbon intensity of fuel declines significantly as low-carbon fuels, such as cellulosic ethanol and renewable biodiesel, comprise a higher proportion of fuel use.

The Rapid Fire model was designed to calculate emissions that occur upon fuel combustion ("tank-to-wheel" emissions), as well as those emitted during the full fuel lifecycle, from extraction and processing to transport and storage ("well-to-wheel" emissions). Users can look to either or both; typically, emission inventories compare tank-to-wheel emissions, although full well-to-wheel assessments are critical to developing climate change mitigation strategies. The Rapid Fire model is able to calculate both types of emission rates based on fuel mix assumptions, enabling an analysis of the role of fuel carbon intensity standards in meeting GHG reduction goals. More often, though, users will opt to model tank-to-wheel emissions on the basis of a baseline carbon intensity factor and projected reductions from it to each horizon year.

Fuel and other Driving Costs

The Rapid Fire model estimates three components of transportation costs, including fuel, auto ownership, and tires and maintenance. These costs are calculated separately using different assumptions. Fuel costs are calculated by multiplying fuel consumed by fuel price per gallon. Auto ownership and tire and maintenance costs are each calculated by multiplying VMT by an average price-per-mile factor. All per-gallon and per-mile prices change year upon year according to horizon-year projections.

Pricing Effects

Because fuel price, along with other driving costs, have been shown to have both short- and long-term effects on driving decisions, the Rapid Fire model allows users the option to "turn on" sensitivity to changes in per-mile driving costs to estimate changes in VMT due to pricing. Research into historic patterns has quantified relationships among the interrelated factors of VMT and automobile fuel economy with costs including fuel price and taxes; automobile ownership, insurance, and maintenance costs; and parking, toll, and congestion charges. The results, expressed as an "elasticity" of change in one factor with respect to change in another, can be used to estimate the effects of specific policy- or program-based assumptions on VMT.

The Rapid Fire model calculates residential and commercial building energy use for both new and existing buildings. Scenarios vary in their building energy use profiles due to their building program and policy-based assumptions about improvements in energy efficiency.

Residential Energy Consumption

Residential energy use in the Rapid Fire model is calculated as a function of three basic sets of assumptions: a) average base-year energy use for existing units; b) base-year (2005) energy use for new units by building type; and c) reductions in building energy use resulting from advances in building energy efficiency policy and technology.

Energy Use of Base/Existing Buildings

Average per-household energy use for existing units is derived from total residential sector electricity and gas use and number of housing units in the baseline year (2005). The energy used by the population of existing units is expected to decline over time, as buildings are replaced, retrofitted, or upgraded. The extent of future energy savings due to each of these conditions are determined by user-specified rates.

Energy Use of New Buildings

Energy use for new units is calculated using per-unit factors for annual electricity and gas use. Reductions are applied to the baseline factors to reflect the assumption that, year-upon-year, new construction will be built to meet higher efficiency standards. It is also expected that new buildings can see further improvement over the time span of the model (for instance, a building built in 2011 may be retrofit by 2035 to meet even higher standards). The application of the energy use reduction assumptions applied to both new and existing units is shown in the flow chart on the following page.

Commercial Energy Consumption

As for residential energy use, commercial energy use in the Rapid Fire model is calculated as a function of three basic sets of assumptions: a) per-employee floorspace factors, b) baseline (2005) energy intensity factors, and c) reductions in building energy use resulting from advances in building energy efficiency policy and technology.

Energy Use of Base/Existing Buildings

Average per-square foot energy use for existing commercial buildings is derived from total commercial sector electricity and gas use and a floorspace estimate for the baseline year (2005). The energy used by existing buildings is expected to decline over time, as buildings are replaced, retrofitted, or upgraded. The extent of future energy savings due to each of these conditions are determined by user-specified rates.

Energy Use of New Buildings

Energy use for new commercial floorspace is calculated using per-square foot energy intensity factors for annual electricity and gas use. Reductions are applied to the baseline factors to reflect the assumption that, year-upon-year, new construction will be built to meet higher efficiency standards. It is also expected that new buildings can see further improvement over the time span of the model (for instance, a building built in 2011 may be retrofit by 2035 to meet even higher standards). The application of the energy use reduction assumptions applied to both new and existing units is shown in the flow chart on the following page.

The amount of new commercial space in each scenario is calculated using assumptions about the number of employees by commercial space type (office, retail, or warehouse), and the amount of floorspace required per employee in each of the three Land Development Categories. Floorspace requirements are highest in the Standard LDC, and lowest in the Urban LDC. The number of employees by type, which is held constant for all scenarios, is projected based on demographic assumption inputs.

Baseline Annual Household Energy Use by Building Type*

Large Lot Single Family	Small Lot Single Family	Attached Single Family	Multifamily
100 million Btu	71 million Btu	54 million Btu	38 million Btu

** California averages, including residential electricity and natural gas use. Derived from the California Energy Commission Statewide Residential Appliance Saturation Survey (RASS), 2004.*

Baseline Residential Energy Use. *Because larger homes require more energy to heat and cool, home size is generally correlated with a household's overall energy consumption. Scenarios with a greater proportion of the Standard Land Development Category, which include primarily single-family detached homes, will require more energy – and produce more GHG emissions – than scenarios with a greater proportion of Compact or Urban areas, which include more attached and multifamily homes. Energy use also varies by climate zone, which can be reflected in the Rapid Fire model.*

Total Buildings
Base / Existing Buildings
(Residential Units or Commercial Floorspace)
Growth Increment Buildings
(Residential Units by Type or Commercial Floorspace)
Replacement Rate
Non-Replaced Buildings
Replacement Buildings
Energy Use Reduction Factors
Upgrade Efficiency Factor 'A'
Efficiency improvements and conservation measures
New Efficiency Factor 'B'
New construction standards
New Efficiency Factor 'D'
New construction standards
Upgrade Efficiency Factor 'C'
Ongoing efficiency improvements and conservation measures
Upgrade Efficiency Factor 'E'
Ongoing efficiency improvements nad conservation measures
ENERGY USE OF BASE / EXISTING BUILDINGS
ENERGY USE OF NEW/INCREMENT BUILDINGS
ANNUAL ENERGY USE OF TOTAL BUILDINGS

Greenhouse Gas Emissions

Building GHG emissions include total emissions from residential and commercial electricity and natural gas use. Emission results are calculated based on energy consumption and emission rates, which are assumed to vary according to the mix of resources used to generate energy. The baseline and projected emission rates are measured per unit of energy consumed (kilowatt-hour or therm), and include carbon dioxide, methane, and nitrous oxide emissions in units of carbon dioxide equivalent (CO_2e). The same emission rates are applied to the energy used by residential and commercial buildings.

Emission Rate Assumptions

Projections are made for the horizon years of 2020, 2035, and 2050, with rates following a straight-line trend in between. The emission rate for electricity generation can be expected to decline over time, while that for natural gas use can be expected to remain constant. As with all Rapid Fire assumptions, users can enter different inputs to test the results of different policy-based projections, for instance comparing the effects of achieving California's 33% Renewables Portfolio Standard (RPS) by 2020, or by a later date.

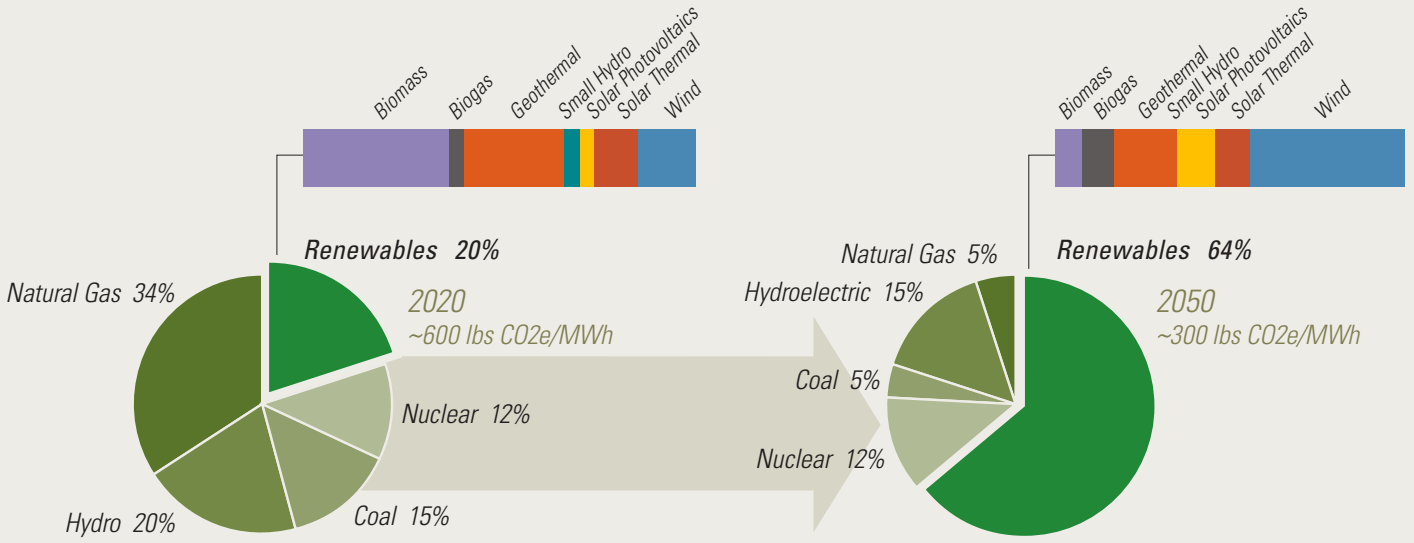
When available, absolute projections based on analyses specific to a state or region should be used. Because emissions from electricity are subject to a number of interrelated variables that can affect resource mix and emission rates into the future – including fuel price and availability, generation costs, energy use efficiency, the market penetration of renewable energy technologies, and the amount of electricity imported from other areas – rates are technically challenging to estimate. In the absence of such projections, users can enter emission rate projections calculated as simple percentage reductions from the baseline emission rate.

Energy Costs

Residential and commercial energy costs are calculated on the basis of energy use and price assumptions. The model applies separate retail price factors to residential and commercial electricity and natural gas use. Price projection assumptions are expressed in constant dollars, and like all assumptions are entered for the horizon years of 2020, 2035, and 2050. Between horizon years, prices are assumed to follow a straight-line trend.

Electricity prices are expected to increase over time, in response to changes in the portfolio mix and other factors such as the cost of electricity generation resources, various infrastructure costs, overall supply and demand, and potential regulations. Electricity price projections can be estimated to correspond generally with the portfolio mix inherent to the chosen GHG emission rate assumptions, or estimated as simple percentage increases over the baseline price. Natural gas price projections can be estimated similarly.

Resource Mix and Emission Rates. *Electricity greenhouse gas (CO_2e) emissions vary based on the mix of resources used. As the share of clean and renewable energy sources in the electricity generation portfolio is increased, the average electricity emission rate will decrease. Electricity emissions are estimated based on assumed rates in 2020, 2035, and 2050. The diagram below illustrates a hypothetical move toward a cleaner portfolio and lower emission rate.*



Water Consumption

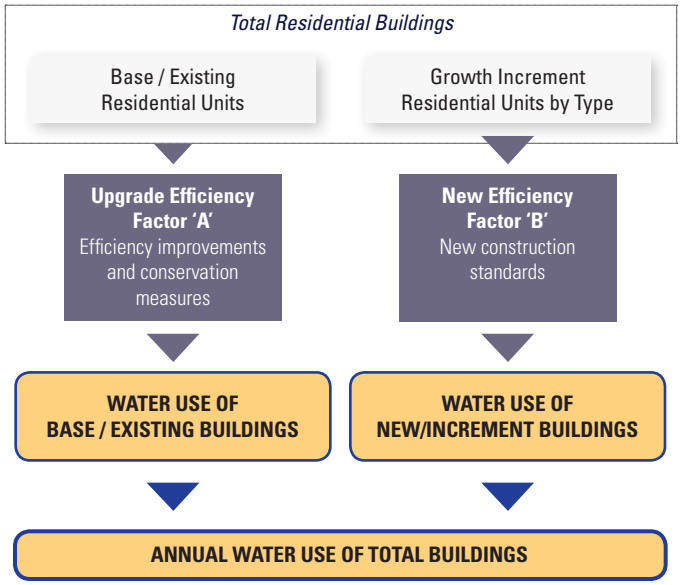
Residential water use in the Rapid Fire model is calculated as a function of three basic sets of assumptions: a) average base-year water use for existing units; b) base-year (2005) water use for new units by building type; and c) reductions in building water use resulting from advances in water efficiency policy and technology.

Water Use of Base/Existing Buildings

Average per-household water use for existing units is derived from total residential sector water use and housing units for the baseline year (2005). The energy used by the population of existing units is expected to decline over time, as water-saving measures are implemented. The extent of future energy savings due to each of these conditions are determined by user-specified rates – expressed as percentage reductions from baseline use – to each horizon year.

Water Use of New Buildings

Water use for new units is calculated using annual per-unit usage factors, which vary by building type. Reductions are applied to the baseline factors to reflect the assumption that, year-upon-year, new homes will be built with the technology to meet higher efficiency standards. It is also expected that new buildings can see further improvement over the time span of the model (for instance, a building built in 2011 may be upgraded by 2035 to meet even higher standards). The application of the water use reduction assumptions applied to both new and existing units is represented in the flow chart below.



Water Costs

Residential water costs are calculated on the basis of water use and retail water price assumptions. Water price projections are expressed in constant dollars per acre-foot, and like all assumptions are made for the horizon years of 2020, 2035, and 2050. Between horizon years, prices are assumed to follow a straight-line trend.

Water prices are expected to increase over time in response to limited supply and the potential application of pricing strategies to promote water conservation. Users can make absolute price assumptions based on specific policies, or assume a year-upon-year rate of increase.

GHG Emissions from Water-Related Energy Use

Water-related GHG emissions result from two main categories of energy use: a) system uses, including the transport, treatment, and distribution of water consumed; and b) end uses, including all uses of water that occur within homes (e.g., water heating).[22] The Rapid Fire model 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.

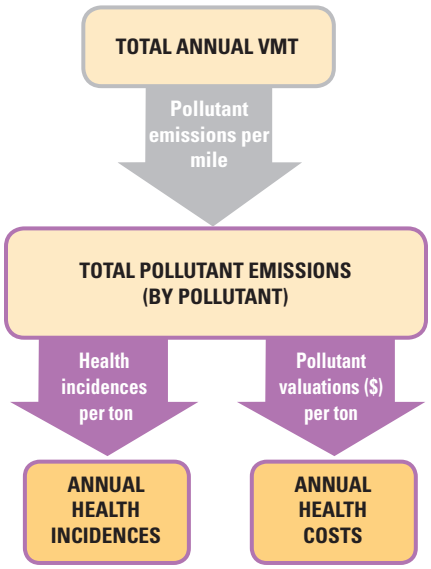
Baseline Water Use. *Because larger homes with larger yards require more water for landscape irrigation, lot size is generally correlated with a household's overall water consumption. Scenarios with a greater proportion of the Standard Land Development Category, which include primarily single-family detached homes, will require more water – and produce more GHG emissions – than scenarios with a greater proportion of Compact or Urban areas, which include more attached and multifamily homes. Outdoor water needs also vary with climate. For California, the Rapid Fire model estimates outdoor water needs according to reference evapotranspiration (climate-based irrigation factors) for different geographic areas.*

2005 Annual Household Water Use by Building Type*

Large Lot Single Family	Small Lot Single Family	Attached Single Family	Multifamily
194,000 gal	125,000 gal	93,000 gal	89,000 gal

** California statewide baseline average consumption figures include indoor and outdoor water use. Indoor use is based on per-capita averages; outdoor use is based on generalized assumptions about landscape area and irrigation requirements.*

The Rapid Fire model calculates the public health impacts of automobile transportation-related air pollution. The number of health incidences, and their related costs, are calculated on the basis of criteria air pollutant emissions (measured in tons).[3] Note that these metrics express differences among scenarios, rather than as measurements of total health incidences or costs.



Health Incidences

Health incidences include cases of: premature mortality; chronic bronchitis; acute myocardial infarction; respiratory and cardiovascular hospitalizations; respiratory-related ER visits; acute bronchitis; work loss days; asthma exacerbation; and acute, lower, and upper respiratory symptoms. Per-ton assumptions for each of these incidences are individually applied to emissions of the following criteria pollutants: PM2.5, SOx, NOx, and VOC. The incidences are then totaled.

Health Costs

Health costs are based on per-ton valuations of emissions of the following pollutants: PM2.5, SOx, NOx, CO, VOC, and indirect PM from NOx, SOx, and VOC. As for health incidences, these valuations are applied to emissions of individual pollutants, and then totaled.

MODEL RESULTS

Viewing Model Results

Users can view model outputs through the model's static results summary (the "Results" sheet) or the automated interface of the "Interactive Results" sheet. The automated interface allows users to customize the results display according to the following parameters:

- Horizon year (2020, 2035, or 2050)
- Annual (single-year) or cumulative (multiple-year leading up to horizon year) metrics
- Total, per capita, or per household basis for metrics
- Comparison of annual metrics against historic baseline year (1990 or 2005)

Below is a sample view of the "Interactive Results" sheet.

RESULTS (Interactive)

Study Area: United States

1	Select a horizon year for which to show results:	☐ 2020	☐ 2035	☒ 2050
2	Select ANNUAL or CUMULATIVE results:	☒ Annual	☐ Cumulative	
3	Select total, per capita, or per household results:	☐ TOTAL	☐ per Capita	☒ per Household
4	Select a historical baseline year against which to compare selected horizon year results:	☐ 1990	☒ 2005	
5	Click to see results:	CLICK for RESULTS		
6	If needed, return to Policy Option Selection worksheet to change policy options.	Return to POLICY OPTIONS		

2050
ANNUAL
per Household
2005

Demographics	1990	2005	2020	2035	2050
Population	*248,709,873*	*296,410,404*	*341,387,000*	*389,531,000*	*439,010,000*
Households	*91,947,410*	*111,090,617*	*127,744,591*	*145,759,734*	*164,274,424*

Go to Total Annual Metrics

Go to Total Cumulative Metrics

Selected Policies: Auto and Fuel Technology Option B (Medium); Building Efficiency Option B (Medium); Utility Portfolio Option B (Medium)	Absolute Values/Results 2050				Difference from Trend 2050						Difference from 2005 historic baseline 2050			
	TREND	CONSERVATIVE	SMART	ULTRA SMART	CONSERVATIVE		SMART		ULTRA SMART		TREND		CONSERVATIVE	
Total Greenhouse Gas (GHG) Emissions														
Total Emissions (Transportation and Buildings) (MMT)	2,287.8 MMT	2,072.5 MMT	1,759.5 MMT	1,695.6 MMT	-215.3 MMT	-9%	-528.3 MMT	-23%	-592.2 MMT	-26%	-1,396.3 MMT	-38%	-1,611.6 MMT	-44%
Transportation Emissions (ICE Fuel Lifecycle)	720.7 MMT	559.7 MMT	351.4 MMT	314.5 MMT	-160.9 MMT	-22%	-369.3 MMT	-51%	-406.2 MMT	-56%	-739.7 MMT	-51%	-900.7 MMT	-62%
Building Emissions (Residential and Commercial)	1,567.1 MMT	1,512.8 MMT	1,408.1 MMT	1,381.1 MMT	-54.3 MMT	-3%	-159.0 MMT	-10%	-186.1 MMT	-12%	-656.6 MMT	-30%	-710.9 MMT	-32%
Land Consumption														
Land Consumed (sq mi)	34,981 sq mi	27,250 sq mi	11,485 sq mi	4,932 sq mi	-7,732 sq mi	-22%	-23,497 sq mi	-67%	-30,049 sq mi	-86%	*34,981 sq mi*	*37%*	*27,250 sq mi*	*29%*
Transportation*														
VMT (miles)	1,968.5 B mi	1,528.9 B mi	959.9 B mi	859.1 B mi	-439.6 B mi	-22%	-1,008.6 B mi	-51%	-1,109.4 B mi	-56%	-791.4 B mi	-29%	-1,231.0 B mi	-45%
Fuel Consumed (gal)	70.6 B gal	54.8 B gal	34.4 B gal	30.8 B gal	-15.8 B gal	-22%	-36.2 B gal	-51%	-39.8 B gal	-56%	-68.7 B gal	-49%	-84.5 B gal	-61%
Fuel Cost ($)	$564.1 B	$438.1 B	$275.1 B	$246.2 B	-$126.0 B	-22%	-$289.0 B	-51%	-$317.9 B	-56%	$403.7 B	252%	$277.7 B	173%
Auto Ownership and Maintenance Cost ($)														
Transportation Electricity Consumed (kWh)	53,593 GWh	41,625 GWh	26,133 GWh	23,389 GWh	-11,968 GWh	-22%	-27,460 GWh	-51%	-30,204 GWh	-56%				
Transportation Electricity Cost ($)	$9.8 B	$7.6 B	$4.8 B	$4.3 B	-$2.2 B	-22%	-$5.0 B	-51%	-$5.5 B	-56%				
Transportation Electricity Emissions (MMT)	19.4 MMT	15.1 MMT	9.5 MMT	8.5 MMT	-4.3 MMT	-22%	-10.0 MMT	-51%	-11.0 MMT	-56%				
ICE Fuel Combustion Emissions (MMT)	565.1 MMT	438.9 MMT	275.6 MMT	246.6 MMT	-126.2 MMT	-22%	-289.6 MMT	-51%	-318.5 MMT	-56%	-594.9 MMT	-51%	-721.1 MMT	-62%
ICE Full Fuel Lifecycle Emissions (MMT)	720.7 MMT	559.7 MMT	351.4 MMT	314.5 MMT	-160.9 MMT	-22%	-369.3 MMT	-51%	-406.2 MMT	-56%	-739.7 MMT	-51%	-900.7 MMT	-62%
Criteria Pollutant Emissions (tons)	150 tons	117 tons	73 tons	66 tons	-34 tons	-22%	-77 tons	-51%	-85 tons	-56%				
Building Energy														
Residential Energy Consumed (Btu)	5,026.9 tril Btu	4,825.0 tril Btu	4,408.2 tril Btu	4,300.8 tril Btu	-201.8 tril Btu	-4%	-618.7 tril Btu	-12%	-726.1 tril Btu	-14%	-5,823.1 tril Btu	-54%	-6,025.0 tril Btu	-56%
Commercial Energy Consumed (Btu)	6,774.4 tril Btu	6,316.6 tril Btu	5,457.0 tril Btu	5,234.3 tril Btu	-457.8 tril Btu	-7%	-1,317.4 tril Btu	-19%	-1,540.2 tril Btu	-23%	-1,480.6 tril Btu	-18%	-1,938.4 tril Btu	-23%
Total Energy Consumed (Btu)	11,801.3 tril Btu	11,141.7 tril Btu	9,865.2 tril Btu	9,535.1 tril Btu	-659.6 tril Btu	-6%	-1,936.1 tril Btu	-16%	-2,266.2 tril Btu	-19%	-7,303.7 tril Btu	-38%	-7,963.3 tril Btu	-42%
Residential Building Emissions (MMT)	1,022.6 MMT	1,005.1 MMT	969.5 MMT	960.3 MMT	-17.5 MMT	-2%	-53.1 MMT	-5%	-62.3 MMT	-6%	-183.8 MMT	-15%	-201.3 MMT	-17%
Commercial Building Emissions (MMT)	544.6 MMT	507.8 MMT	438.7 MMT	420.7 MMT	-36.8 MMT	-7%	-105.9 MMT	-19%	-123.8 MMT	-23%	-472.7 MMT	-46%	-509.5 MMT	-50%
Residential Energy Cost ($)	$552.1 B	$542.9 B	$524.4 B	$519.6 B	-$9.1 B	-2%	-$27.7 B	-5%	-$32.5 B	-6%		134%		130%
Water														
Water Consumed (AF)	26,394,972,065 AF	26,393,015,235 AF	26,389,335,101 AF	26,388,390,734 AF	-1,956,831 AF	0%	-5,636,964 AF	0%	-6,581,332 AF	0%				
Water Cost ($)	$38,357.3 B	$38,354.5 B	$38,349.1 B	$38,347.8 B	-$2.8 B	0%	-$8.2 B	0%	-$9.6 B	0%				
Water-Related Electricity Use (GWh)	71,301,708 GWh	71,296,422 GWh	71,286,481 GWh	71,283,930 GWh	-5,286 GWh	0%	-15,227 GWh	0%	-17,778 GWh	0%				
Water-Related Electricity Emissions (MMT)	25,873.5 MMT	25,871.6 MMT	25,868.0 MMT	25,867.1 MMT	-1.9 MMT	0%	-5.5 MMT	0%	-6.5 MMT	0%				
Infrastructure														
Infrastructure Cost ($)	$3,136.5 B	$2,505.8 B	$1,522.2 B	$1,522.2 B	-$630.7 B	-20%	-$1,614.4 B	-51%	-$1,614.4 B	-51%				

Interactive Results Sheet. *Results are automatically displayed according to the parameters selected.*

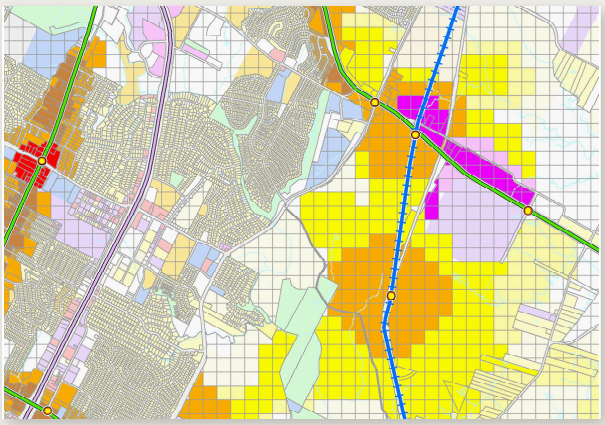
THE VISION CALIFORNIA PROCESS

The development and application of the Rapid Fire model is part of the Vision California process, an unprecedented effort to explore the role of land use and transportation investments in meeting the environmental, fiscal, and public health challenges facing California over the coming decades. Funded by the California High Speed Rail Authority (*cahighspeedrail.ca.gov*) and the California Strategic Growth Council (*www.sgc.ca.gov*), Vision California will:

- Highlight the unique opportunity presented by California's planned High Speed Rail network in shaping growth and other investments.
- Frame California's development issues in a comprehensive manner, illustrating the role of land use in meeting greenhouse gas (GHG) reduction targets through robust analysis.
- Illustrate the connections between land use and other major challenges, including water and energy use, housing affordability, public health, farmland preservation, infrastructure provision, and economic development.
- Clearly link land use and infrastructure priorities to mandated targets as set forth by AB 32, SB 375, and the California Air Resources Board (CARB).
- Produce scalable tools, for use by state agencies, regions, local governments, and the non-profit community, which can defensibly measure the impacts of land use and transportation investment scenarios.
- Build upon Blueprints and other regional plans to produce statewide growth scenarios that go beyond regional boundaries and assess the combined impact of these plans.
- Connect state and national goals for energy independence, energy efficiency, and green job creation to land use and transportation investments.

Vision California is driven in part by the challenges set forth by the 2006 passage of the California Global Warming Solutions Act (AB 32), which sets aggressive targets for the reduction of greenhouse gas emissions (GHGs). The project is designed to provide critical context for the implementation of Senate Bill 375 (SB 375) and land use-related GHG-reduction targets for local governments, as it will illustrate and comprehensively measure the role of land use and SB 375-mandated regional "Sustainable Communities Strategies" in meeting AB 32 GHG targets.

Two new scenario development and analysis tools are being used to compare physical growth alternatives – the Rapid Fire model, and the 'Urban Footprint' map-based model. These related tools serve distinct purposes: while the spreadsheet-based Rapid Fire model quickly produces metrics that bracket the range of potential impacts, the map-based Urban Footprint model produces a more refined analysis that is greatly sensitive to land use and demographic characteristics.



The Urban Footprint Map-Based Model. *Currently under development, the Urban Footprint model uses geographic information system (GIS) technology to create and evaluate physical land use-transportation investment scenarios. Scenarios are defined through the application of 'Place Types' to the environment. The model's suite of Place Types represents a complete range of development types and patterns, from higher density mixed-use centers, to separated-use residential and commercial areas, to institutional and industrial areas. The physical and demographic characteristics associated with the Place Types are used to calculate the impacts of each scenario. Output metrics will include: land consumption; infrastructure cost (capital as well as operations and maintenance); building energy and water consumption, cost, and associated CO_2 emissions; public health impacts; vehicle miles traveled and all related fuel, GHG, and pollutant emissions; and non-auto travel mode share and other related travel metrics.*

ENDNOTES

Endnotes

1. Consistent with regulatory targets, all assumptions and results for fuel use, fuel economy, and fuel emissions in the Rapid Fire model are expressed in terms of gallons of gasoline equivalent.

2. California's AB 1493 Clean Car Standard and Low-Carbon Fuel Standard, for example, both assume that growing shares of electric and other low-emission vehicles in the on-road fleet are necessary to reach targets.

3. The Rapid Fire model public health assumptions were initially developed by TIAX, LLC for the American Lung Association. Assumptions are based on national data from the EPA, Office of Air Quality Planning & Standards, Air Benefit and Cost Group (August 2010), with valuations (costs) extrapolated for 2035.

BACKGROUND

Rapid Fire Model Output Metrics and Input Assumptions

Summary of Output Metrics

Land Consumption
- Land Consumed (square miles)
- Non-Residential Land Consumed (square miles)

Infrastructure Cost
- Capital Costs for Roads and Wet and Dry Utility Provision ($)
- Operations and Maintenance Costs ($)
- City Revenues from Residential Development ($)

Transportation System Impacts and Emissions
- Vehicle Miles Traveled (VMT) (miles)
- Fuel Consumed (gal)
- Fuel Cost ($)
- Transportation Electricity Consumed (kWh)
- Transportation Electricity Cost ($)
- Transportation Electricity CO_2e Emissions (MMT)
- ICE Fuel Combustion CO_2e Emissions (MMT)
- ICE Full Fuel Lifecycle CO_2e Emissions (MMT)
- Criteria Pollutant Emissions (tons)

Public Health Impacts Related to Transportation Emissions
- Respiratory and Cardiovascular Health Incidences (#)
- Health Costs associated with Health Incidences ($)

Building Energy, Cost, and Emissions
- Residential Energy Consumed (Btu)
- Commercial Energy Consumed (Btu)
- Total Energy Consumed (Btu)
- Residential Building CO_2e Emissions (MMT)
- Commercial Building CO_2e Emissions (MMT)
- Residential Energy Cost ($)
- Building Water Use, Cost, and Emissions
- Water Consumed (AF)
- Water Cost ($)
- Water-Related Electricity Use (GWh)
- Water-Related Electricity CO_2e Emissions (MMT)

Total Greenhouse Gas (GHG) Emissions
- Total CO_2e Emissions (Transportation & Buildings, MMT)

Building Program
- Housing type mix (# and %)

Summary of Input Assumptions

Demographics
- Baseline population and population growth
- Baseline households and household growth
- Baseline housing units and housing unit growth
- Baseline non-farm jobs and job growth

Scenarios
- Land Development Category (LDC) proportions for each scenario and time period
- Housing unit composition for each LDC

Infrastructure Cost
- Per-unit capital cost assumptions for roads and wet and dry utility provision by building type and Land Development Category (LDC)
- Per-unit operations and maintenance cost assumptions for roads, utilities, and public services by building type and LDC
- Per-unit revenue assumptions by building type and LDC

Land Consumption
- Percent greenfield vs. infill/greyfield/brownfield growth for each land development category, scenario, and time period
- Acres per capita required for greenfield development in each land development category, scenario, and time period

Vehicle Miles Traveled (VMT)

- Baseline Per Capita Light Duty Vehicle (LDV) VMT
- VMT adjustment factors by LDC and scenario for growth increment population
- VMT escalation and deceleration rates for the baseline environment population
- Elasticity of VMT with respect to driving costs per mile*

Vehicle Fuel Economy and Cost

- Baseline fuel economy for total fleet, internal combustion engine vehicles alone, and alternative/electric vehicles alone
- Fuel economy in horizon years for total fleet, internal combustion engine vehicles alone, and alternative/electric vehicles alone
- Elasticity of fuel economy with respect to fuel cost

Transportation Emissions

- Baseline fuel emissions, full lifecycle (well-to-wheel) for total fleet, internal combustion engine vehicles alone, and alternative/electric vehicles alone
- Baseline fuel emissions, combustion (tank-to-wheel) for total fleet, internal combustion engine vehicles alone, and alternative/electric vehicles alone
- Percent gasoline vs. diesel in liquid fuel mix
- Composition of gasoline and diesel fuel mix
- Criteria pollutant emissions per mile traveled

Public Health Impacts Related to Transportation Emissions

- Health incidences per ton of pollutant
- Health costs per ton of pollutant

Building Energy Emissions

- Electricity generation emissions (lbs/kWh)
- Natural gas combustion emissions (lbs/therm)
- Electricity generation emissions in horizon years (lbs/kWh)
- Natural gas combustion emissions in horizon years (lbs/therm)

Residential Building Energy Use & Price

- Baselineline average annual energy use per unit for base/existing population
- Annual energy use by building type
- Housing unit replacement rate for base/existing housing stock
- Upgrade efficiency reduction factor 'A' for base/existing housing stock
- New efficiency reduction factor 'B' for replacement units of base/existing housing stock
- Upgrade efficiency reduction factor 'C' for replacement units of base/existing housing stock
- New efficiency factor 'D' for new units of the growth increment
- Upgrade efficiency factor 'E' for new units of the growth increment
- Baseline residential electricity and gas prices
- Residential electricity and gas prices in horizon years

Commercial Building Energy Use & Price

- Non-farm job proportion by floorspace-type category
- Floorspace per employee by category for each LDC
- Commercial space replacement rate for base/existing housing stock
- Baseline average annual energy use per square foot for base/existing commercial space
- Annual baseline energy use for new commercial space
- Replacement rate for base/existing commercial space
- Upgrade efficiency reduction factor for base/existing commercial space
- New efficiency reduction factor for replacement commercial space
- Upgrade efficiency reduction factor for replacement commercial space
- New efficiency factor for new floorspace of the growth increment
- Upgrade efficiency factor for new floorspace of the growth increment
- Baseline commercial electricity and gas prices
- Commercial electricity and gas price in horizon years

Residential Building Water Use

- Baseline per capita indoor water demand by building type
- Baseline per-unit outdoor water demand by building type
- New residential water efficiency (% reduction from 2005)
- Baseline water price ($/acre foot)
- Water price in horizon years ($/acre foot)

Residential Water-Related Energy Use and Emissions

- Average water energy proxy (electricity required per million gallons water used)