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 as part of the Vision California planning process. The Rapid Fire model was designed to produce and evaluate high-level statewide and/or regional scenarios across a range of metrics. This document is intended to impart a fundamental understanding of how Rapid Fire scenarios are formulated and analyzed. A more detailed description of the model, including a step-by-step tour through the model’s user interface and technical information about all model calculations and assumptions, is available in the Rapid Fire White Paper and Technical Guide.

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 and regional 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; 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 and regional 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 (CO₂) emissions from cars and buildings
- Air pollution
- Fuel use and cost
- Building energy use and cost
- Residential water use and cost
- Land consumption
- Infrastructure cost

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.visioncalifornia.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

- Per-capita assumptions by Land Development Category
- Per-unit assumptions by Housing Type
- Per-square foot assumptions

OUTPUT METRICS

- TOTAL GHG EMISSIONS
  - LDV VMT emissions
  - Residential energy use emissions
  - Commercial energy use emissions

- LAND CONSUMPTION METRICS
  - Land consumed: total, per household, and per capita

- INFRASTRUCTURE COST METRICS
  - Infrastructure cost: 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

- 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

- 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.

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

Study Area Selection Sheet. Input data are entered, stored, and loaded from the Study Area Selection sheet.
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](image)
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.

<table>
<thead>
<tr>
<th>Land Use Characteristics</th>
<th>Transportation Infrastructure</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>URBAN</strong></td>
<td>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.</td>
</tr>
<tr>
<td><strong>COMPACT</strong></td>
<td>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.</td>
</tr>
<tr>
<td><strong>STANDARD</strong></td>
<td>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.</td>
</tr>
</tbody>
</table>
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.

Default Housing Mix Assumptions for LDCs

STANDARD LDC

URBAN LDC

COMPACT LDC

SMART GROWTH LDC proportion

“Smart Growth” LDC proportion

STANDARD LDC
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.

### 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 CO2e per kWh)
- Residential & commercial building natural gas emissions (lbs CO2e per therm)

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### 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.
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 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 refill, 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.

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**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.
Infrastructure cost analysis allows users to compare the fiscal impacts of varying forms of development. The Rapid Fire model incorporates cost data from a number of sources to derive infrastructure cost factors on a per-housing unit basis according to land use option. Capital costs for the following infrastructure elements are included:

- Local streets, curbs, gutters, and sidewalks
- Water and sewer systems
- Flood control and drainage systems
- Dry utilities (electricity, gas, phone, and cable)

The per-unit infrastructure costs represent averages for the unit type mix of each land use option. Costs are estimated using per-linear foot cost data for each type of infrastructure. Dispersed development patterns require greater lengths of streets, sewers, and pipes because of the location of new development relative to already developed areas, as well as the distances between homes and other buildings. The default assumptions have been informed by the infrastructure cost results of various regional planning efforts, including the Sacramento Area Council of Government’s Blueprint planning and scenario modeling process.

While the Rapid Fire model does not yet analyze the costs for operations and maintenance, these cost differences are expected to widen as the cost of ongoing maintenance (most often borne by local and regional agencies and operations) is included in future versions of the model. Future versions will also account for the incremental cost of infill and greyfield development and thus produce a more complete picture of infrastructure cost variations among land use patterns.
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. For more detailed information about specific assumptions and their application, please refer to the Rapid Fire Model White Paper and Technical Guide.
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.

**BUSINESS as USUAL**

Standard development exceeds 55%

**MIXED GROWTH**

Neither Standard nor Compact+Urban refill exceed 55%

**SMART GROWTH**

Compact+Urban refill development exceeds 55%

Scenario Tipping Point Range: 45 - 55%

Detailed VMT Assumptions Sheet. Inputs are entered, stored, and loaded from the Study Area Selection sheet.
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, 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, or through the use of separate assumptions for electric and conventional (internal combustion engine) vehicles. More information about how the model estimates electric and alternative vehicle impacts can be found in the Rapid Fire Model White Paper and Technical Guide.

**GHG Emissions**

Transportation GHG emissions are calculated by applying carbon intensity assumptions, expressed in pounds of carbon dioxide equivalent (CO₂e) 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 retrofitted 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*

<table>
<thead>
<tr>
<th>Building Type</th>
<th>Energy Use (mBtu)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Large Lot Single Family</td>
<td>100 mBtu</td>
</tr>
<tr>
<td>Small Lot Single Family</td>
<td>71 mBtu</td>
</tr>
<tr>
<td>Attached Single Family</td>
<td>54 mBtu</td>
</tr>
<tr>
<td>Multifamily</td>
<td>38 mBtu</td>
</tr>
</tbody>
</table>

RESIDENTIAL and COMMERCIAL BUILDING ENERGY

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 and 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\textsubscript{2}e). 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. For a detailed discussion of energy emission rate assumptions and their application in the model, please refer to the Rapid Fire Model White Paper and Technical Guide.

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\textsubscript{2}e) 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). 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*

<table>
<thead>
<tr>
<th></th>
<th>Large Lot Single Family</th>
<th>Small Lot Single Family</th>
<th>Attached Single Family</th>
<th>Multifamily</th>
</tr>
</thead>
<tbody>
<tr>
<td>Consumption</td>
<td>194,000 gal</td>
<td>125,000 gal</td>
<td>93,000 gal</td>
<td>89,000 gal</td>
</tr>
</tbody>
</table>

* 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.
# 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.

### Interactive Results Sheet

Results are automatically displayed according to the parameters selected.

### Study Area: United States

#### Absolute Values/Results

<table>
<thead>
<tr>
<th>Year</th>
<th>Utility</th>
<th>ESP</th>
<th>Smart</th>
<th>Ultra Smart</th>
<th>Smart</th>
<th>Ultra Smart</th>
</tr>
</thead>
<tbody>
<tr>
<td>2035</td>
<td>2,215.9 GWh</td>
<td>2,215.9 GWh</td>
<td>1,765.1 GWh</td>
<td>1,865.1 GWh</td>
<td>251.3 GWh</td>
<td>251.3 GWh</td>
</tr>
<tr>
<td>2050</td>
<td>2,215.9 GWh</td>
<td>2,215.9 GWh</td>
<td>1,765.1 GWh</td>
<td>1,865.1 GWh</td>
<td>251.3 GWh</td>
<td>251.3 GWh</td>
</tr>
</tbody>
</table>

#### Difference from Trend

<table>
<thead>
<tr>
<th>Year</th>
<th>Utility</th>
<th>ESP</th>
<th>Smart</th>
<th>Ultra Smart</th>
<th>Smart</th>
<th>Ultra Smart</th>
</tr>
</thead>
<tbody>
<tr>
<td>2035</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>2050</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
</tbody>
</table>

#### Difference from 2005 historic baseline

<table>
<thead>
<tr>
<th>Year</th>
<th>Utility</th>
<th>ESP</th>
<th>Smart</th>
<th>Ultra Smart</th>
<th>Smart</th>
<th>Ultra Smart</th>
</tr>
</thead>
<tbody>
<tr>
<td>2035</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>2050</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
</tbody>
</table>

### Electricity Policies

#### State and Technology Breakdown (Electricity)

<table>
<thead>
<tr>
<th>Policy Description</th>
<th>2035</th>
<th>2050</th>
<th>2035</th>
<th>2050</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Generation</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transportation</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Building Efficiency</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Smart</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ultra Smart</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
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) in partnership with 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.
**Endnotes**

1. For a thorough description of the Rapid Fire VMT modeling methodology, including an analysis of VMT in sample LDC areas and a discussion of relevant studies, please refer to the *Rapid Fire White Paper and Technical Guide*.

2. 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.

3. 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.
# BACKGROUND

## Rapid Fire Model Output Metrics and Input Assumptions

### Summary of Output Metrics

<table>
<thead>
<tr>
<th>Land Consumption</th>
<th>Infrastructure Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Land Consumed (square miles)</td>
<td>• Cost for roads and wet and dry utilities provision ($)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Transportation System Impacts and Emissions</th>
<th>Building Energy, Cost, and Emissions</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Vehicle Miles Traveled (VMT) (miles)</td>
<td>• Residential Energy Consumed (Btu)</td>
</tr>
<tr>
<td>• Fuel Consumed (gal)</td>
<td>• Commercial Energy Consumed (Btu)</td>
</tr>
<tr>
<td>• Fuel Cost ($)</td>
<td>• Total Energy Consumed (Btu)</td>
</tr>
<tr>
<td>• Transportation Electricity Consumed (kWh)</td>
<td>• Residential Building CO(_2)e Emissions (MMT)</td>
</tr>
<tr>
<td>• Transportation Electricity Cost ($)</td>
<td>• Commercial Building CO(_2)e Emissions (MMT)</td>
</tr>
<tr>
<td>• Transportation Electricity CO(_2)e Emissions (MMT)</td>
<td>• Residential Energy Cost ($)</td>
</tr>
<tr>
<td>• ICE Fuel Combustion CO(_2)e Emissions (MMT)</td>
<td>• Building Water Use, Cost, and Emissions</td>
</tr>
<tr>
<td>• ICE Full Fuel Lifecycle CO(_2)e Emissions (MMT)*</td>
<td>• Water Consumed (AF)</td>
</tr>
<tr>
<td>• Criteria Pollutant Emissions (tons)</td>
<td>• Water Cost ($)</td>
</tr>
<tr>
<td></td>
<td>• Water-Related Electricity Use (GWh)</td>
</tr>
<tr>
<td></td>
<td>• Water-Related Electricity CO(_2)e Emissions (MMT)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Total Greenhouse Gas (GHG) Emissions</th>
<th>Building Program</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Total CO(_2)e Emissions (Transportation &amp; Buildings, MMT)</td>
<td>• Housing type mix</td>
</tr>
</tbody>
</table>

* Denotes an optional output not generated for the scenarios presented in this report.

### Summary of Input Assumptions

<table>
<thead>
<tr>
<th>Demographics</th>
<th>Scenarios</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Baseline population and population growth</td>
<td>• Land Development Category (LDC) proportions for each scenario and time period</td>
</tr>
<tr>
<td>• Baseline households and household growth</td>
<td>• Housing unit composition for each LDC</td>
</tr>
<tr>
<td>• Baseline housing units and housing unit growth</td>
<td></td>
</tr>
<tr>
<td>• Baseline non-farm jobs and job growth</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Infrastructure Cost</th>
<th>Land Consumption</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Cost inputs for roads and wet and dry utilities provision by Land Use Category</td>
<td>• Percent greenfield vs. infill/greyfield/brownfield growth for each land development category, scenario, and time period</td>
</tr>
<tr>
<td></td>
<td>• Acres per capita required for greenfield development in each land development category, scenario, and time period</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Vehicle Miles Traveled (VMT)</th>
<th>Vehicle Fuel Economy and Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Baseline Per Capita Light Duty Vehicle (LDV) VMT</td>
<td>• Baseline fuel economy for total fleet, internal combustion engine vehicles alone*, and alternative/electric vehicles alone*</td>
</tr>
<tr>
<td>• VMT adjustment factors by LDC and scenario for growth increment population</td>
<td>• Fuel economy in horizon years for total fleet, internal combustion engine vehicles alone*, and alternative/electric vehicles alone*</td>
</tr>
<tr>
<td>• VMT escalation and deceleration rates for the baseline environment population</td>
<td>• Elasticity of fuel economy with respect to fuel cost*</td>
</tr>
<tr>
<td>• Elasticity of VMT with respect to driving costs per mile*</td>
<td></td>
</tr>
</tbody>
</table>

* Denotes an optional input which was not applied in calculating the output metrics presented in this report.
<table>
<thead>
<tr>
<th><strong>Transportation Emissions</strong></th>
<th><strong>Building Energy Emissions</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>- Baseline fuel emissions, full lifecycle (well-to-wheel) for total fleet, internal combustion engine vehicles alone*, and alternative/electric vehicles alone*</td>
<td>- Electricity generation emissions (lbs/kWh)</td>
</tr>
<tr>
<td>- Baseline fuel emissions, combustion (tank-to-wheel) for total fleet, internal combustion engine vehicles alone*, and alternative/electric vehicles alone*</td>
<td>- Natural gas combustion emissions (lbs/therm)</td>
</tr>
<tr>
<td>- Percent gasoline vs. diesel in liquid fuel mix</td>
<td>- Electricity generation emissions in horizon years (lbs/kWh)</td>
</tr>
<tr>
<td>- Composition of gasoline and diesel fuel mix</td>
<td>- Natural gas combustion emissions in horizon years (lbs/therm)</td>
</tr>
<tr>
<td>- Criteria pollutant emissions per mile traveled</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Residential Building Energy Use &amp; Price</strong></th>
<th><strong>Commercial Building Energy Use &amp; Price</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>- Baseline average annual energy use per unit for base/existing population</td>
<td>- Non-farm job proportion by floorspace-type category</td>
</tr>
<tr>
<td>- Annual energy use by building type</td>
<td>- Floorspace per employee by category for each LDC</td>
</tr>
<tr>
<td>- Housing unit replacement rate for base/existing housing stock</td>
<td>- Commercial space replacement rate for base/existing housing stock</td>
</tr>
<tr>
<td>- Upgrade efficiency reduction factor 'A' for base/existing housing stock</td>
<td>- Baseline average annual energy use per square foot for base/existing commercial space</td>
</tr>
<tr>
<td>- New efficiency reduction factor 'B' for replacement units of base/existing housing stock</td>
<td>- Annual baseline energy use for new commercial space</td>
</tr>
<tr>
<td>- Upgrade efficiency reduction factor 'C' for replacement units of base/existing housing stock</td>
<td>- Replacement rate for base/existing commercial space</td>
</tr>
<tr>
<td>- New efficiency factor 'D' for new units of the growth increment</td>
<td>- Upgrade efficiency reduction factor for base/existing commercial space</td>
</tr>
<tr>
<td>- Upgrade efficiency factor 'E' for new units of the growth increment</td>
<td>- New efficiency reduction factor for replacement commercial space</td>
</tr>
<tr>
<td>- Baseline residential electricity price</td>
<td>- Upgrade efficiency reduction factor for replacement commercial space</td>
</tr>
<tr>
<td>- Baseline residential gas price</td>
<td>- New efficiency factor for new floorspace of the growth increment</td>
</tr>
<tr>
<td>- Residential electricity price in horizon years</td>
<td>- Upgrade efficiency factor for new floorspace of the growth increment</td>
</tr>
<tr>
<td>- Residential gas price in horizon years</td>
<td>- Baseline commercial electricity price</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Residential Building Water Use</strong></th>
<th><strong>Residential Water-Related Energy Use and Emissions</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>- Baseline per capita indoor water demand by building type</td>
<td>- Average water energy proxy (electricity required per million gallons water used)</td>
</tr>
<tr>
<td>- Baseline per-unit outdoor water demand by building type</td>
<td></td>
</tr>
<tr>
<td>- New residential water efficiency (% reduction from 2005)</td>
<td></td>
</tr>
<tr>
<td>- Baseline water price ($/acre foot)</td>
<td></td>
</tr>
<tr>
<td>- Water price in horizon years ($/acre foot)</td>
<td></td>
</tr>
</tbody>
</table>

* Denotes an optional input which was not applied in calculating the output metrics presented in this report.