California Energy Demand Scenario Projections to 2050

Ryan McCarthy
Christopher Yang
Joan Ogden

Institute of Transportation Studies
University of California, Davis

An input for the Advanced Energy Pathways project
Public Interest Energy Research Program
California Energy Commission

November 7, 2006

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

AC	Air conditioner
AEO	Annual Energy Outlook
AEP	Advanced Energy Pathways
BGP	Burbank, Glendale, and Pasadena
CARB	California Air Resources Board
CalCARS	California Light Duty Vehicle Conventional and Alternative Fuel Response Simulator
CEC	California Energy Commission
DOF	Department of Finance
DWR	Department of Water Resources
EIA	Energy Information Administration
EMFAC	Emission Factor (Emission inventory model)
EUI	Energy use intensity
FE	Fuel economy
GBN	Global Business Network
GETF	Global Environment and Technology Foundation
GSP	Gross state product
GWh	Gigawatt-hour
HH	Household
IEPR	Integrated Energy Policy Report (biennial report published by the CEC)
LADWP	Los Angeles Department of Water and Power
LDV	Light-duty vehicle
LLNL	Lawrence Livermore National Laboratory
LNG	Liquefied natural gas
MFHH	Multi-family households
MPG	Miles per gallon
NAICS	North American Industrial Classification System
PG&E	Pacific Gas & Electric
PIER	Public Interest Energy Research (program of the California Energy Commission)
PPH	Persons per household
SCE	Southern California Edison
SCG	Southern California Gas
SDGE	San Diego Gas and Electric
SFGSP	Shipment fraction of GSP
SFHH	Single-family household
SIC	Standard Industrial Classification
SMUD	Sacramento Municipal Utility District
TWh	Terawatt-hour
UCB	University of California, Berkeley
UCD	University of California, Davis
UEC	Unit energy consumption
VMT	Vehicle-miles traveled
VSTM	Vehicle stock turnover model
WH	Water heater

EXECUTIVE SUMMARY

Introduction

This report describes five alternative scenarios for future energy demands in California, developed at UC Davis as part of the Advanced Energy Pathways (AEP) project.

The Advanced Energy Pathways is a project of the California Energy Commission's (CEC) Public Interest Energy Research (PIER) Program, with contributing researchers from the University of California, Davis (UCD); Lawrence Livermore National Laboratory (LLNL); Global Environment and Technology Foundation (GETF); and the University of California, Berkeley (UCB). The primary objective of the AEP is to analyze the impacts of alternative transportation energy pathways on California's natural gas and electricity sectors through the year 2050.

The scenarios presented here are intended to span a wide range of possible energy demand futures for California and provide an energy demand context for AEP's analyses of integrated energy supply strategies. In this report we present a methodology for scenario development that enables us to quantify the electricity, natural gas, and transportation fuel demands between 2005 and 2050 for a range of demographic, economic, and technical assumptions. The scenarios provide transparent estimates of future energy demands that will feed into subsequent energy systems modeling. These future AEP studies will model future energy supplies and infrastructure in California to determine how these demands, as well as additional energy demands due to advanced transportation fuels and technologies, will be met.

Scenario Descriptions

We present five energy demand scenarios that span a wide range of demographic, economic and technology assumptions for California through the year 2050. The main drivers for each of the energy demands are population, per-capita activity (e.g., vehicle miles per person), and efficiency (e.g., vehicle fuel economy). For natural gas and electricity, the demand for individual sectors (residential, commercial, industrial, agricultural, and *other*) is projected individually, then aggregated to provide total state-wide demands. Transportation fuel demand is calculated separately for light-duty vehicles, heavy-duty vehicles and aircraft.

Three of the scenarios are distinct, representing baseline, maximum, and minimum demands. The *Baseline demand* scenario develops energy demand projections by continuing recent and projected near-term trends for each of the drivers, while *Minimum demand* and *Maximum demand* incorporate assumptions that attempt to minimize or maximize total energy demands, respectively.

Two additional scenarios are presented to explore sensitivities around the *Baseline demand* scenario. These adopt identical demographic and economic assumptions as the baseline, but vary other parameters to project higher or lower demand. For electricity and natural gas, these two scenarios (called *Baseline – high efficiency* and *Baseline – low efficiency*) explore the sensitivity of the *Baseline demand* scenario to changes in efficiency. For transportation fuel demand, all parameters other than demographics and economics vary in the moderate scenarios (*Baseline – low demand* and *Baseline – high demand*), capturing the impact of several assumptions on *Baseline demand* (including the distribution of vehicle types in the fleet, vehicle-miles traveled, and fuel efficiency).

The scenario assumptions are summarized in Tables ES-1 and ES-2.

Table ES-1 Summary of electricity and natural gas scenario assumptions.

Scenario	Demographics	Economics	Efficiency
Maximum demand	Year 2050 pop. = 70 million;[b] Decreasing household size, more single family homes	Avg. annual GSP growth = 3.74%	Frozen at current levels, or very minor improvement
Baseline - low efficiency	Year 2050 pop. = 55 million;[a] Continuation of current household trends	Avg. annual GSP growth = 2.75%	Frozen at current levels, or very minor improvement
Baseline demand			Continued historical and projected near-term trends
Baseline - high efficiency			Technically feasible improvements (with today's technology)
Minimum demand	Year 2050 pop. = 45 million; Increasing household size, fewer single family homes	Avg. annual GSP growth = 1.05%	Technically feasible improvements (with today's technology)

GSP = Gross State Product, DOF = California Department of Finance
[a] DOF (2004)

Table ES –2 Summary of transportation fuel demand scenario assumptions

Scenario	Fleet characteristics		Year 2050 VMT per-capita	Year 2050 fleet-avg. fuel economy
Maximum demand	82 million vehicles in 2050;	Increasing truck share	12,376	23 mpg
Baseline – high demand	51 million vehicles in 2050;	Increasing truck share	12,916	24 mpg
Baseline demand		Constant truck share	10,833	26 mpg
Baseline – low demand		Decreasing truck share	8,434	32 mpg
Minimum demand	30 million vehicles in 2050;	Decreasing truck share	5,583	49 mpg

Electricity Demands

The total electricity demand for each of the scenarios is presented in Figure ES-1. Also shown on the figure is the CEC's electricity projection from the 2005 Integrated Energy Policy Report (IEPR2005). As expected, the *Baseline Demand* scenario tracks the IEPR projection to 2016, and shows continued growth to 2050. The two *Baseline Demand* side-cases illustrate the relatively modest potential for energy efficiency to slow the growth of statewide electric demand. The *Minimum Demand* and *Maximum* Demand cases show a wide variation in annual electricity demand, from 217,000 GWh to 688,000 GWh in 2050. This factor-of-three difference illustrates the multiplicative impacts of population growth, per-capita activity growth and technology and efficiency assumptions on total energy demand. Compared to *Baseline Demand-High efficiency, Minimum demand* shows a 20% reduction in electricity demand despite growth (albeit slow) in population and the state economy. *Maximum demand* shows a very large increase in electricity demand because of population growth, growth in economic and activity drivers (such as industrial shipments and commercial floorspace), and minor increases in energy efficiency.

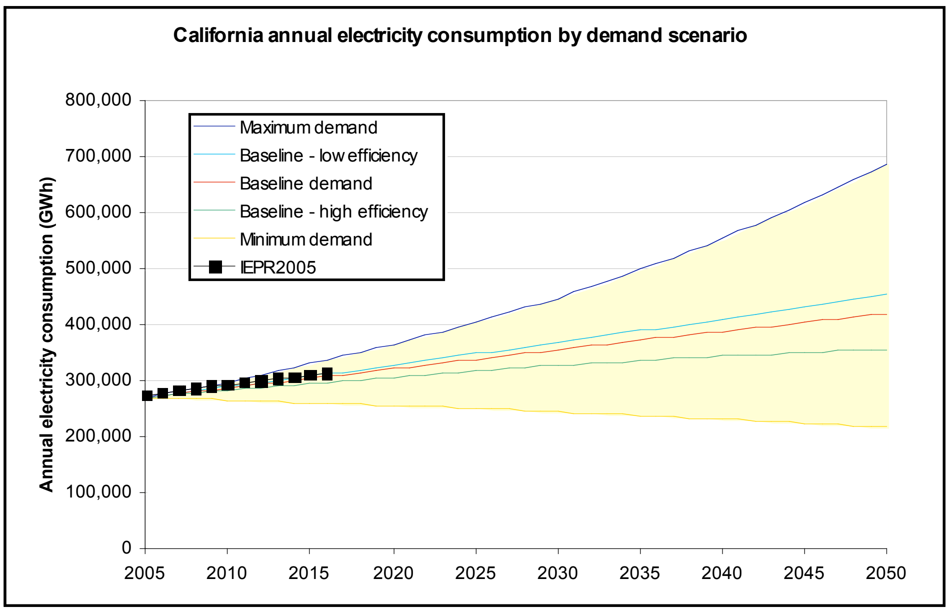


Figure ES-1 Annual electricity demand for each alternative scenario.

Per-capita electricity consumption (see Figure ES-2) is projected to increase an average of 0.63% annually in *Maximum demand*, to 9,836 kWh/year in 2050, and 0.24% per-year in *Baseline - low efficiency*, to 8,280 kWh/year. *Baseline - high efficiency* and *Minimum demand* see average annual reductions in per-capita electricity consumption of 0.29% and 0.94%, respectively, to 6,514 kWh/year and 4,853 kWh/year in 2050.

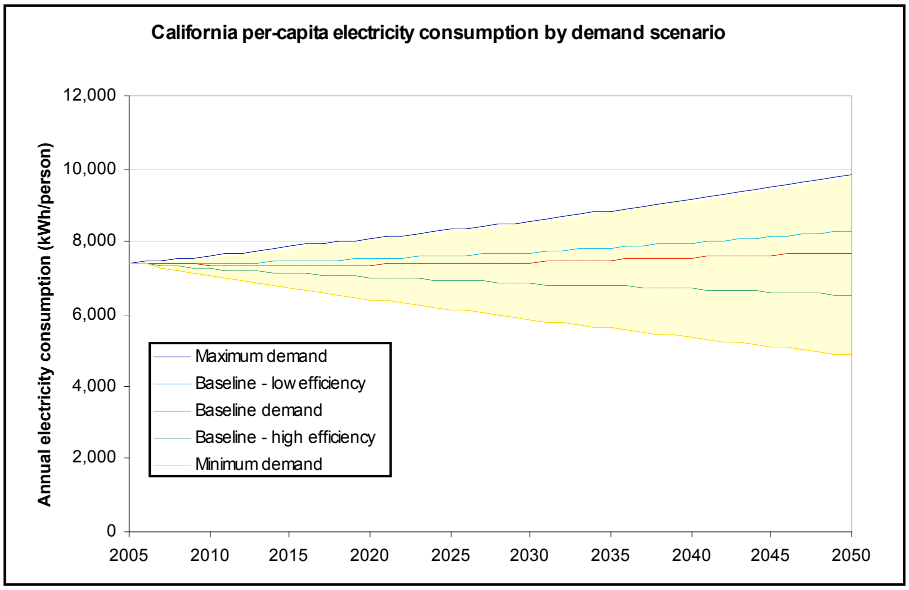


Figure ES-2 California annual per-capita electricity consumption by demand scenario.

Natural Gas Demands

Figure ES-3 shows natural gas demands in California for each of the alternative scenarios to 2050. Natural gas demand varies from 8,800 to 37,400 million therms in 2050. Much of the four-fold difference between the *Minimum demand* and *Maximum demand* scenarios, and the difference between *Maximum demand* and *Baseline - low efficiency,* can be attributed to the significant differences in industrial shipment assumptions that are linked to economic growth. As shown by the electricity and natural gas demands in the three *Baseline Demand* cases, the impact of energy efficiency changes is relatively small compared to the effects of changes in population and economic growth.

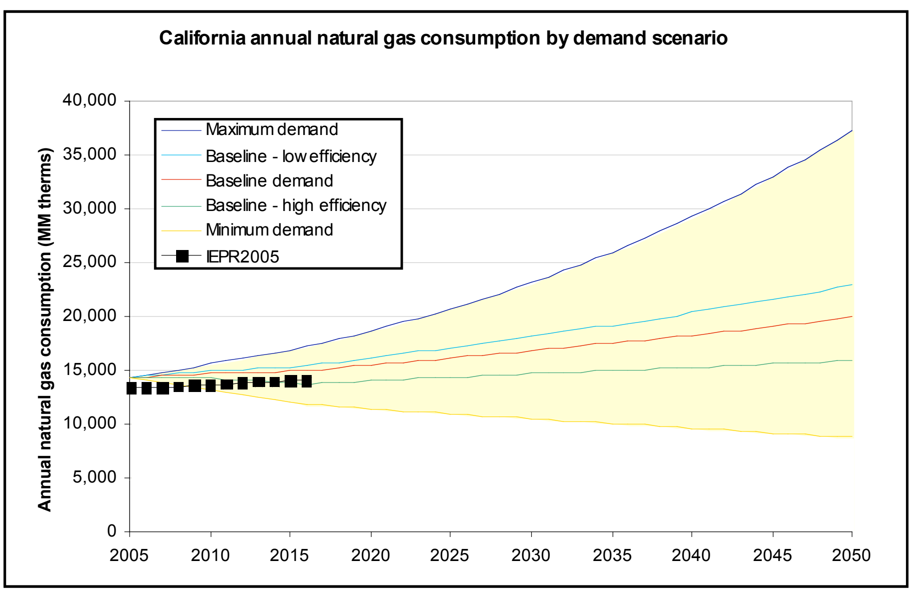


Figure ES-3 Annual natural gas demand for each alternative scenario.

Per-capita natural gas consumption is illustrated in Figure ES-4 for the alternate scenarios. In the *Baseline demand* scenario, year 2050 per-capita consumption is 8% below current levels. *Minimum demand* sees a 50% reduction in per-capita consumption by 2050, while in *Maximum demand*, consumption increases 35% per-capita by 2050. *Baseline – low efficiency* and *Baseline – high efficiency* see an increase in per-capita consumption of 6% and a reduction of 26%, respectively, by 2050. These sensitivity-scenarios illustrate the range of efficiency assumptions included in the natural gas projections.

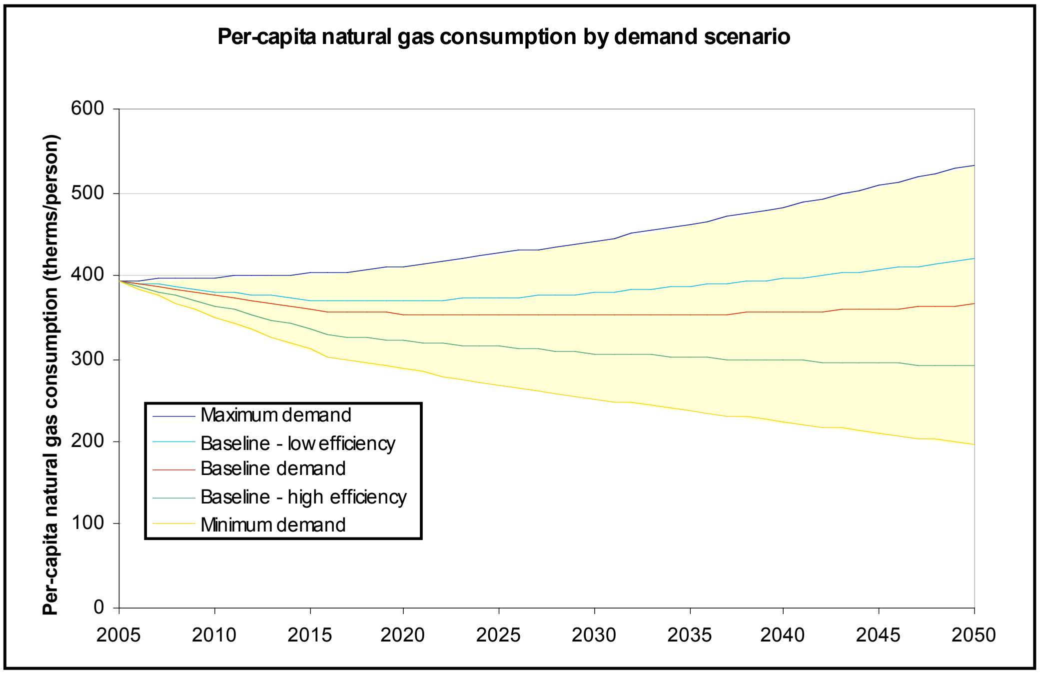


Figure ES-4 Per-capita natural gas consumption for each alternative scenario.

Transportation Fuel Demands

Figures ES-5 and ES-6 show the transportation fuel demand and per-capita fuel demand in California for each of the alternative scenarios out to 2050. Also shown on Figure ES-5 is the IEPR2005 fuel demand projection to 2025, which is matched and then extended to 2050 in the *Baseline demand* scenario. The key drivers for transportation fuel demand are population, vehicle miles traveled per-capita, fuel economy, and sales distribution by vehicle type. Transportation fuel shows the most significant variation between the highest and lowest demands of any of the three energy demands, in part because of the significant reductions assumed possible in *Minimum demand*. The fuel demand reduction is dependent upon very large vehicle efficiency improvements that were assumed possible for light-duty vehicles and an assumed significant decline in travel demand. Out of the seven-fold change in demand between the extreme scenarios for light-duty vehicles (six-fold for total fuel usage including heavy-duty and aircraft demand), the fuel economy and travel demand (VMT/capita) assumptions account for approximately a factor of four.

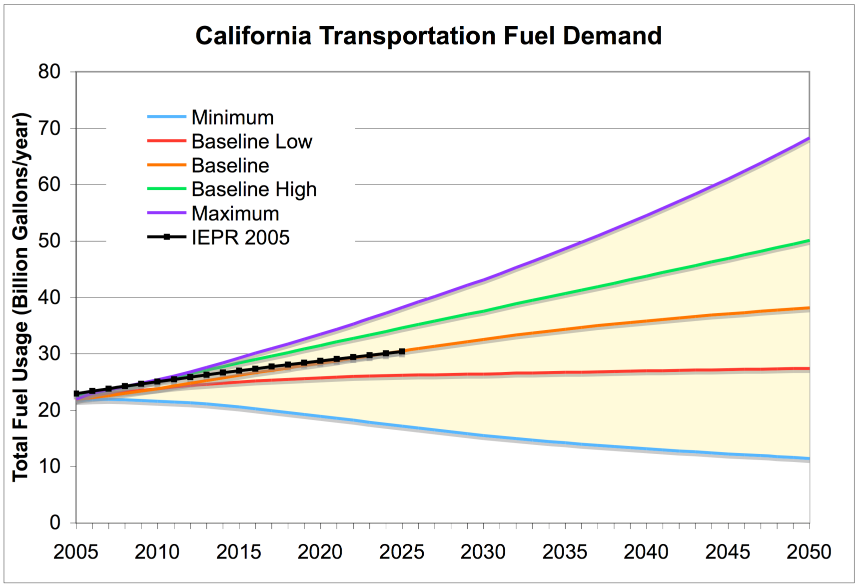


Figure ES-5 Annual transportation fuel demand for each alternative scenario.

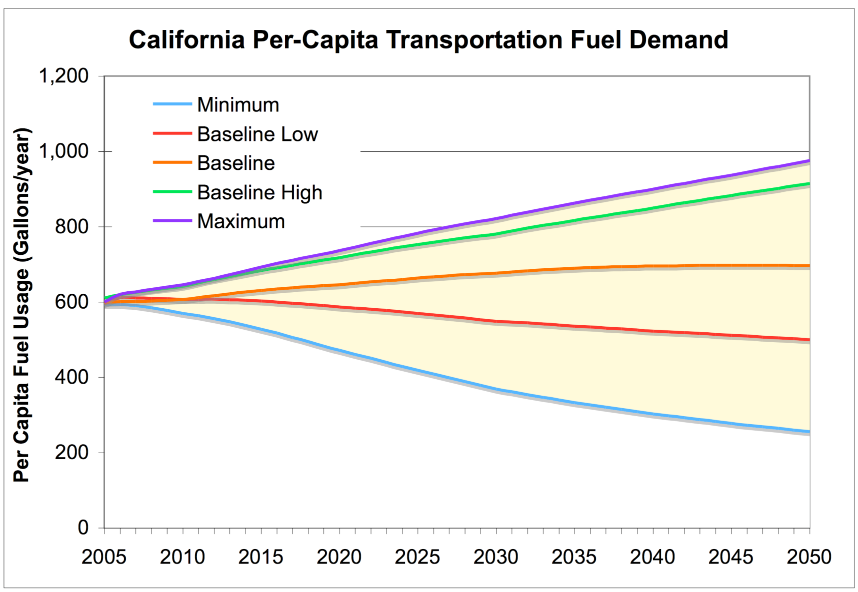


Figure ES-6 Annual per-capita transportation fuel demand for each alternative scenario.

Summary

This scenario report and accompanying spreadsheets provide the annual demand for electricity, natural gas and transportation fuel from 2005 to 2050 for five scenarios that span a wide range of demographic, economic and technology development assumptions. The report covers the methods and assumptions for generating energy demands for each energy type and sector. The level of future energy demand has important implications on future energy supplies for California, with respect to availability of resources, cost and reliability of energy services, and environmental implications for meeting energy demand. The range of scenarios developed here and their associated energy demands is quite large, which provides a useful set of inputs into the energy system modeling to assess these issues.

1. INTRODUCTION

This report covers the development of energy demand scenarios for California as part of the Advanced Energy Pathways (AEP) project. It extends (and modifies) the baseline demand scenario projections reported previously (McCarthy et al., 2006).

Advanced Energy Pathways is a project of the California Energy Commission's (CEC) Public Interest Energy Research (PIER) Program, with contributing researchers from the University of California, Davis (UCD); Lawrence Livermore National Laboratory (LLNL); Global Environment and Technology Foundation (GETF); and the University of California, Berkeley (UCB). The primary objective of the project is to analyze the impacts of alternative transportation energy pathways on California's natural gas and electricity sectors through the year 2050. Many of the transportation energy pathways represent new paradigms (based on hydrogen fuel cell vehicles or plug-in hybrid electric vehicles, for example) that require significant changes to the current transportation fuel supply infrastructure and impact demand for existing energy resources – electricity and natural gas. The AEP project quantifies the impacts of such changes on the State's energy systems using scenario analysis.

Impacts of interest include CO_2 emissions, resource consumption (especially natural gas and renewables), and marginal energy supply costs. They will be evaluated at each year from 2005 to 2050 on an hourly basis for a set of energy demand and supply scenarios. This report describes the demand scenarios that will be included in the modeling. They will be used as inputs to a LLNL computer model that will optimize the structure and operation of California's energy supply system given various supply scenario assumptions (e.g., a high Renewable Portfolio Standard).

It is useful to have several demand scenarios that span the range of total energy demands to include in the modeling effort. Five scenarios are described for electricity, natural gas, and conventional light-duty vehicle (LDV) transportation fuels consumption through the year 2050. The scenarios reflect different energy futures that might develop within the State, and encompass feasible ranges in the underlying demographic, economic, and technical parameters. They do not consider specific demographic, economic, political, or social events or trends explicitly (such as oil price shocks or environmental impacts of climate change), despite the fact that realizing some of the scenarios could require a significant shift in public perception or policy.

While we do not consider *how* the scenarios might materialize, the Global Business Network (GBN) has developed a set of narratives that describe three alternate scenarios for California (Mintzer et al, 2006). Their work describes various climatic, economic, political, and social events and trends, and hypothesizes how they might shape California over the next half century. We attempt to quantify the GBN scenarios in Appendix C, using the same framework as for the development of our demand scenarios. However, it is important to note that we do not model them with the full detail presented in the GBN narratives.

Aside from the baseline demand scenario described previously (McCarthy et al, 2006) – and revised here – we provide alternate scenario estimates for maximum, minimum, and moderate energy demand cases. The *Baseline demand* scenario provides a set of possible energy demand growth curves that are based upon extensions of current trends, assuming no significant policy or demographic shifts. The *Baseline demand* scenario provides a reference point to understand the impact of large-scale shifts in technology, demographics, and/or policy. The *Maximum demand* and *Minimum demand* cases represent a convergence of presumed maxima and minima in all the relevant underlying assumptions. The moderate scenarios bracket *Baseline demand* – using similar demographic and economic assumptions, but varying energy efficiency and other parameters – and result in energy demands that are less extreme than the minimum and maximum cases. These scenarios provide a wide range of possible energy demands, which is useful as a basis for the energy systems modeling.

The light-duty vehicle (LDV) transportation fuel demand scenarios presented in this report do not include the alternative energy pathways (such as hydrogen and electric vehicles). These will be investigated in a later phase of the AEP project. Rather, they encompass a range of demands for conventional fuels (gasoline, diesel, and ethanol as an additive) based on existing commercial technologies (e.g., conventional internal combustion engine vehicles and hybrids) and various demographic, economic, and efficiency assumptions. These "background" scenarios will be modified to include alternative fuel demand scenarios (which will describe the trajectory of vehicle adoption and alternative fuel demand) later in the project.

Also, as these scenarios are intended as inputs for later modeling to investigate alternative energy supply strategies and the parameters that affect them, we do not explicitly include endogenous factors such as income- or price-elasticity of demand (although they may be captured to some extent implicitly, in our data sources). These issues might be addressed in the subsequent modeling.

2. OUTPUTS

The primary output from this work is detailed quantitative projections of major energy demands within California through 2050 for five alternate demand scenarios and the three GBN scenarios. They are organized into Microsoft Excel® spreadsheets that contain temporally- and spatially-disaggregated data series for electricity, natural gas, and transportation fuels. The electricity and natural gas projections are broken down into five sectors: residential, commercial, industrial, agricultural, and *other* (which includes transportation, communications, and utilities).

Each spreadsheet is annotated to provide the user with information regarding the derivation of the scenarios, the projection methods, and the critical underlying assumptions. The spreadsheets also contain graphs comparing the scenarios at several levels of aggregation. Table 1 lists the spreadsheets containing the scenario demand projections, and describes the outputs contained therein.

Table 1. Output files for AEP scenario demand projections.

Filename	Description
Electricity_AEPscenarios.xls	• Annual electricity consumption by sector and region • Annual peak electricity demand by sector • Demographic and economic projections
Hourlydemand_AEPscenarios.xls	• Hourly electricity demands by sector
Naturalgas_AEPscenarios.xls	• Annual natural gas consumption by sector and region • Annual peak-month natural gas demand • Demographic and economic projections
Transportation_AEPscenarios.xls	• Annual, monthly and hourly transportation fuels demands • Annual vehicle miles traveled • LDV fleet average fuel economy (mpg) • Annual new car sales by vehicle class and type

3. METHODOLOGY

The energy demand scenarios capture variations in underlying demographic, economic, and energy usage parameters. Our *Baseline demand* scenario derives from existing CEC projections for the next 10-20 years developed as part of the biennial Integrated Energy Policy Report (IEPR), and extends those trends through 2050. Our alternate scenarios begin with historical data, and projecting forward, vary the underlying demographic, economic, and technical parameters within feasible ranges. Reasonable parameter ranges were defined based on literature review and consultation with experts in the field.

In general, we project electricity, natural gas, and transportation fuel energy use as the product of energy intensity (e.g., electricity use per household) and the level of activity (e.g., number of households). Activity levels are based upon assumed demographic and economic parameters for each scenario. Energy intensities are based on scenario assumptions regarding energy efficiency improvements. We do not model specific efficiency drivers over the long-term – such as policy mandates, the introduction of specific technologies, or price elasticities of demand – rather, many projections are based upon assumed annual growth rates based on historical data and existing near-term projections. Many such drivers are modeled implicitly, however, based upon detailed sector-specific sources we use for our energy intensity projections over the next 10-20 years.

Detailed discussion of the methods used to project electricity, natural gas, and transportation fuels demand follows in the sections below, and in the Appendix.

3.1. CEC projections

The CEC regularly develops and updates energy demand projections for electricity, natural gas, and transportation fuels. These forecasts typically extend 10-20 years into the future. We extend the trends found in those projections to 2050 to develop our *Baseline demand* scenario. The CEC forecasts and reports used in developing the baseline demand scenario are listed in Table 2. We used projections supporting IEPR2005 when available, and used those from IEPR2003, otherwise (CEC, 2005d; CEC, 2003d).

Table 2. CEC reports used for *Baseline demand* scenario projections.

<table>
<tr><th>Reference</th><th>Timeframe</th><th>Parameter</th><th>Sector</th></tr>
<tr><td rowspan="4">CEC, 2003a</td><td rowspan="4">2003-2013</td><td>Floorspace</td><td>Commercial</td></tr>
<tr><td>Electricity EUI</td><td>Commercial
Industrial
Agricultural
Other</td></tr>
<tr><td>Natural gas EUI</td><td>All</td></tr>
<tr><td rowspan="2">Shipments</td><td rowspan="2">Industrial</td></tr>
<tr><td rowspan="2">CEC, 2005a</td><td rowspan="2">2006-2016</td></tr>
<tr><td>Electricity EUI</td><td>Residential</td></tr>
<tr><td rowspan="4">CEC, 2005e</td><td rowspan="4">2005-2025</td><td>VMT</td><td>Transportation</td></tr>
<tr><td>Vehicle stock</td><td>Transportation</td></tr>
<tr><td>Fuel economy</td><td>Transportation</td></tr>
<tr><td>Fuel demand</td><td>Transportation</td></tr>
</table>

* EUI = energy use intensity; VMT = vehicle miles traveled

The state is divided into 16 climate zones to account for variable heating and cooling loads.[1] These are aggregated into seven electricity utility planning regions,[2] which in turn are aggregated into four natural gas utility planning areas. We project sectoral demands in each of the seven planning areas for electricity and in each of the four planning areas for natural gas. Demand is projected for the residential sector at a more refined level, in terms of climate zones for electricity, and in terms of the electricity planning areas for natural gas.[3] For the purposes of aggregating sectoral electricity demands into a state-wide total, we convert climate zone-specific residential electricity demands into electricity planning area demands, and natural gas demands at the electricity planning area level into natural gas planning area demands, according to the relationships defined in Table 3.

Table 3. Regional classification in CEC forecasts and demand scenarios.

<table>
<tr><th>Climate zone</th><th>Electricity planning area</th><th>Natural gas planning area</th></tr>
<tr><td>Climate zone 1
Climate zone 2
Climate zone 3
Climate zone 4
Climate zone 5</td><td>Pacific Gas & Electric (PG&E)</td><td rowspan="2">PG&E</td></tr>
<tr><td>Climate zone 6</td><td>Sacramento Municipal Utility District (SMUD)</td></tr>
<tr><td>Climate zone 7
Climate zone 8
Climate zone 9
Climate zone 10</td><td>Southern California Edison (SCE)</td><td rowspan="3">Southern California Gas (SCG)</td></tr>
<tr><td>Climate zone 11
Climate zone 12</td><td>Los Angeles Department of Water and Power (LADWP)</td></tr>
<tr><td>Climate zone 16</td><td>Burbank, Glendale, and Pasadena (BGP)</td></tr>
<tr><td>Climate zone 13</td><td>San Diego Gas & Electric (SDGE)</td><td>SDGE</td></tr>
<tr><td>Climate zone 14
Climate zone 15</td><td>Other utilities</td><td>Other utilities</td></tr>
</table>

3.2. Other data sources

We use a similar framework for the alternate scenarios as for the baseline demand scenario, described in CEC (1996, 2005b), but incorporate variable demographic, economic, market, and technology trends. We define these trends based on a review of the relevant literature. The data sources for the projections in the alternate scenarios are listed in Table 4.

[1] The climate zones referred to here are those used by the CEC in their energy forecasts for the state. They differ from the 16 climate zones defined by the Title 24 Building Standards.

[2] An eighth electricity utility area, the Department of Water Resources (DWR), is defined only for water pumping in the agricultural sector.

[3] The level of regional disaggregation reflects the availability of such data. For example, considering natural gas, we do not have climate zone-specific data for the residential sector, but we do have more refined data for the sector (i.e., energy intensity by electricity utility) than we have for any of the other natural gas demand sectors, which are disaggregated by the natural gas utility planning areas.

Table 4. Data sources for alternate demand scenario projections.

Reference	Timeframe	Parameter	Sector	Demand scenario
DOF, 2004	2000-2050	Population (county)	All	*Baseline – low efficiency* *Baseline* *Baseline – high efficiency*
Landis and Reilly, 2003	2003-2100	Population (state)	All	*Maximum*
DOF, 2006	2000-2006	PPH (county)	Residential	All
		% SFHH (county)	Residential	*Baseline – low efficiency* *Baseline* *Baseline – high efficiency*
Quantum/Itron, 2006	2005-2050	% SFHH (state)	Residential	*Maximum* *Minimum*
		Elec. EUI (CZ)	Residential	All
CEC, 2005c	2005-2016	NG EUI (state)	Residential	*Baseline – high efficiency* *Minimum*
CEC, 2005c	2005-2016	Elec. & NG EUI (state)	Commercial	*Baseline – high efficiency* *Minimum*
USGBC, 2005	N/A			
KEMA, 2006	2005-2016	Elec. EUI (state)	Industrial	All
EIA, 2006	2006-2030	Elec. & NG EUI (US)		
Itron et al, 2006	2005-2016	NG EUI (state)		
EIA 2006	2005-2030	Heavy duty fuel economy	Transportation	All
		Aircraft fuel economy		

PPH = persons per household, % SFHH = percent of households that are single-family dwellings,
CZ = climate zone, EUI = energy use intensity

3.3. Scenario Descriptions

We develop five alternative scenarios for energy demand in California through 2050. Three of the scenarios are distinct, representing baseline, maximum, and minimum demands. Two additional scenarios are presented as variations to the baseline scenario. These adopt identical demographic and economic assumptions as the baseline, but vary other parameters to project higher or lower demand for the same baseline demographic and economic future. For electricity and natural gas, these two scenarios illustrate the sensitivity of the baseline scenario to changes in efficiency assumptions. For transportation fuel demand, all parameters other than demographics and economics vary, capturing the impact on *Baseline demand* of changes in several assumptions (including the distribution of vehicle types in the fleet, vehicle-miles travelled, and fuel efficiency).

3.3.1. Electricity and natural gas scenarios

We consider five alternate demand scenarios for electricity and natural gas consumption in California. Three are independent, while the other two quantify the sensitivity of demand to efficiency assumptions. The latter two scenarios incorporate baseline demographic and economic assumptions, but vary the efficiency assumptions:

- *Maximum demand*
- *Baseline - low efficiency*

- *Baseline demand*
- *Baseline - high efficiency*
- *Minimum demand*

The assumptions underlying each scenario are described generally in Table 5. More detailed discussion regarding the development of each scenario follows in subsequent sections.

Table 5. Summary of electricity and natural gas scenario assumptions.

Scenario	Demographics	Economics	Efficiency[d]
Maximum demand	Year 2050 pop. = 70 million;[b] Decreasing PPH; Increasing %SFHH	Avg. annual GSP growth = 3.74%	Frozen at current levels, or very minor improvement
Baseline - low efficiency	Year 2050 pop. = 55 million;[a] Continuation of current household trends	Avg. annual GSP growth = 2.75%	Frozen at current levels, or very minor improvement
Baseline demand	Year 2050 pop. = 55 million;[a] Continuation of current household trends	Avg. annual GSP growth = 2.75%	Continued historical and projected near-term trends
Baseline - high efficiency	Year 2050 pop. = 55 million;[a] Continuation of current household trends	Avg. annual GSP growth = 2.75%	Technically feasible improvements (with today's technology)
Minimum demand	Year 2050 pop. = 45 million;[c] Increasing PPH; Decreasing %SFHH	Avg. annual GSP growth = 1.05%	Technically feasible improvements (with today's technology)

PPH = persons per household, %SFHH = percent single family households, GSP = Gross State Product, DOF = California Department of Finance
[a] DOF (2004)
[b] Presumed maximum California population growth, from Landis and Reilly (2003)
[c] Assumes annual population growth rate = ½ of annual growth rate in *Baseline demand*
[d] Efficiency assumptions were modified in some of the transportation scenarios.

The *Baseline demand* scenario continues near-term market and efficiency trends projected by the CEC, assuming they persist through 2050. We do not postulate this as the most likely future for California. But it provides a useful point of comparison to changes realized through alternatives to current trends. The *Minimum demand* and *Maximum demand* cases represent a convergence of presumed minima or maxima in each of the relevant parameters. For example, the *Minimum demand* scenario captures the effects of slow population and economic growth along with maximum feasible efficiency improvements. Conversely, *Maximum demand* combines the greatest population and economic growth with minimum efficiency improvements. We recognize that many parameters are likely coupled, and again, we do not suppose the likelihood of these scenarios. But we believe that they reasonably bound future energy consumption, barring major unforeseeable policy or social transformations.

Baseline - high efficiency and *Baseline - low efficiency* assume the same demographic and economic parameters as *Baseline demand*, but vary the level of future efficiency improvements. These two scenarios adopt the efficiency assumptions of *Minimum demand* and *Maximum demand* scenarios, and illustrate the sensitivity of future energy demands to efficiency alone.

Three other scenarios, adapted from narrative descriptions developed by GBN, are quantified in Appendix C.

3.3.2. Transportation fuel scenarios

We also develop five alternate scenarios for California transportation fuel demands through 2050. These are listed below:

- *Maximum demand*
- *Baseline – high demand*
- *Baseline demand*
- *Baseline – low demand*
- *Minimum demand*

As for the electricity and natural gas scenarios, *Maximum demand* and *Minimum demand* are based upon a set of input assumptions that intend to place high and low bounds on future energy consumption in the state. All of the scenarios use the same demographic and economic assumptions as the electricity and natural gas scenarios.

However, unlike the electricity and natural gas scenarios, the moderate transportation fuel scenarios (i.e., *Baseline – high demand* and *Baseline – low demand*) do not simply represent the sensitivity of the *Baseline demand* scenario to efficiency assumptions (here, fuel economy). Rather, they vary several important drivers compared to the baseline, only maintaining similar demographic and economic assumptions (thus the total vehicles number of vehicles in each of the three scenarios is the same).

One reason for this difference, relative to the electricity and natural gas scenarios, is that fuel economy increases only slightly in the *Baseline demand* scenario (given that it is a continuation of historical and projected near-term trends). Thus, it is difficult to reasonably bound *Baseline* fuel demand based on efficiency alone. *Baseline – high demand* and *Baseline – low demand* still attempt to bound energy demand for the demographic and economic assumptions in *Baseline demand*, but vary parameters other than just efficiency to do so.

Table 6 summarizes the transportation fuel demand scenario assumptions used in our modeling, which are described in greater detail in *Section 7* below.

Table 6. Summary of transportation fuel demand scenario assumptions

Scenario	Fleet characteristics	Year 2050 VMT per-capita	Year 2050 fleet-avg. fuel economy
Maximum demand	82 million vehicles in 2050; Increasing truck share	12,376	23 mpg
Baseline – high demand	51 million vehicles in 2050; Increasing truck share	12,916	24 mpg
Baseline demand	51 million vehicles in 2050; Constant truck share	10,833	26 mpg
Baseline – low demand	51 million vehicles in 2050; Decreasing truck share	8,434	32 mpg
Minimum demand	30 million vehicles in 2050; Decreasing truck share	5,583	49 mpg

4. DEMOGRAPHICS AND ECONOMICS

4.1. Population

We project county-level population growth through 2050 for each of the demand scenarios. *Baseline demand*, *Baseline - low efficiency*, and *Baseline - high efficiency* use county-level population projections through 2050 developed by the California Department of Finance (DOF) (DOF, 2004). *Minimum demand* assumes an annual population growth rate equal to half of that in *Baseline demand. Maximum demand* assumes state population grows at a constant annual rate of 1.45% and reaches 70 million in 2050, the high end of population growth forecasts by Landis and Reilly (2003).

Figure 1 summarizes the state-wide population forecasts for each scenario. The *Baseline demand* scenario forecasts about 55 million residents in 2050. In *Maximum demand* and *Minimum demand*, year 2050 population is 70 million and about 45 million, respectively.

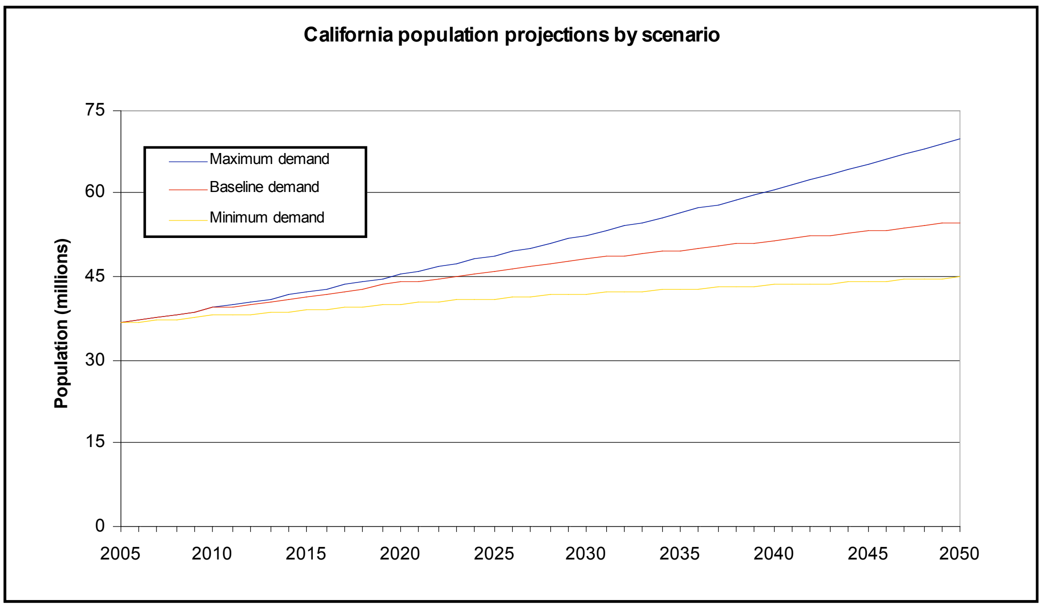


Figure 1 California population projections by demand scenario.

We assume the regional share of state population (by climate zone) remains constant throughout the scenarios, as regional variability was found to have little effect on residential- and commercial-sector energy consumption.

4.2. Households

Projections for the number of households are derived at the county level from the population projections and historical county-level household characteristics from the DOF (2006). They are illustrated in Figure 2. We project 18.2 million households state-wide in *Baseline demand*, 25.8 million in *Maximum demand*, and 13.1 million in *Minimum demand.*

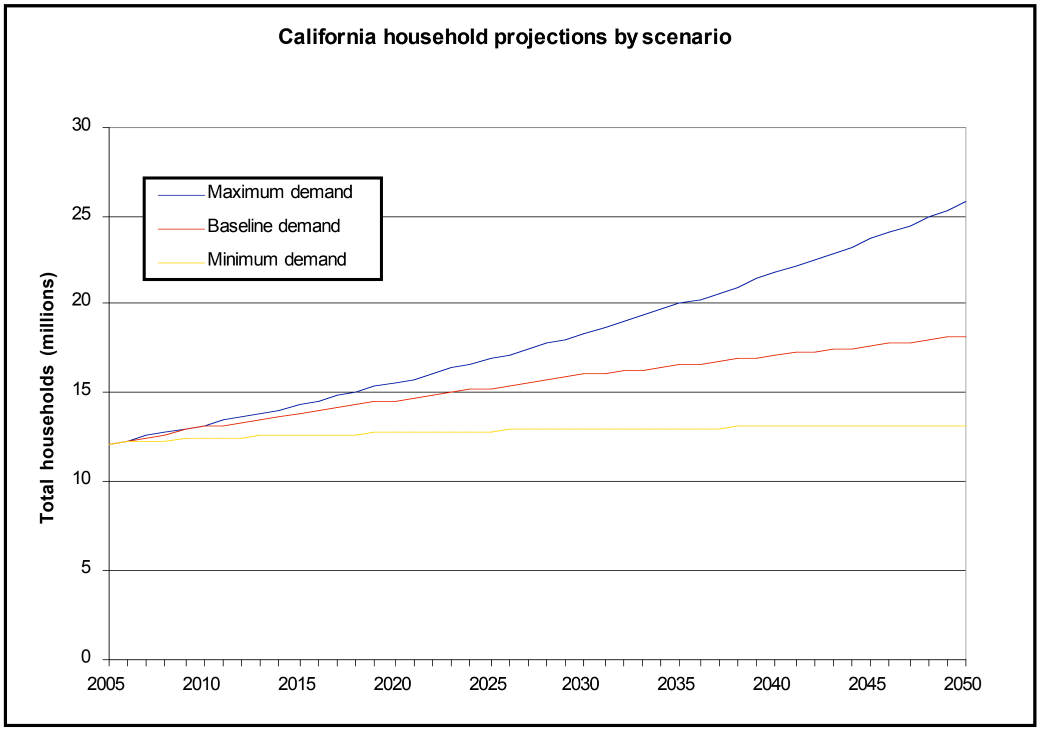


Figure 2 California household projections by demand scenario.

We project the number of two types of households – single-family (SFHH) and multi-family (MFHH) – at the county level using scenario population forecasts and assumptions regarding the percentage of population living in households, the number of persons-per-household (PPH), and the percent of households that are single-family dwellings (% SFHH):

$$\text{No. SFHH} = \sum_{county} \frac{(\text{Population})\begin{pmatrix}\text{Percent of pop.}\\ \text{living in households}\end{pmatrix}\begin{pmatrix}\text{Percent of households}\\ \text{that are single - family}\end{pmatrix}}{\text{Avg. \# persons per household}} \qquad (1)$$

$$\text{No. MFHH} = \sum_{county} \frac{(\text{Population})\begin{pmatrix}\text{Percent of pop.}\\ \text{living in households}\end{pmatrix}\left(1-\begin{pmatrix}\text{Percent of households}\\ \text{that are single - family}\end{pmatrix}\right)}{\text{Avg. \# persons per household}} \qquad (2)$$

Baseline demand uses the DOF population forecasts and assumes that the household characteristics remain constant at year 2006 levels. Under these assumptions, 69% of new houses are constructed as single-family dwellings, and the state-wide average PPH remains essentially constant, at 2.96. *Maximum demand* and *Minimum demand* incorporate deviations from current household trends that lead to greater or lesser energy consumption, respectively. In the *Maximum demand* case, half of new homes (built after 2006) that are built as MFHH in *Baseline demand* are built as SFHH (i.e., 85% percent of new homes are built as single-family dwellings). The opposite is true for *Minimum demand* – half of new homes that are built as SFHH in *Baseline demand* are built as MFHH (i.e., 35% of new homes are built as single-family dwellings). Under these assumptions, the share of SFHH in 2050 reaches 77.3% in *Maximum demand* and 63.0% in *Minimum demand*.

The number of persons per household varies by scenario, as well, amplifying the differences in number of households beyond population variations. In *Maximum demand*, county-level PPH trends linearly to 2.65 in 2050, equal to the lowest current-year value among counties with a population above the state-wide median county population (Sacramento County). County-level PPH trends linearly to 3.33 in 2050 in *Minimum demand*, equal to the highest current-year value among counties above the median population (San Bernardino county). County-level PPH stays constant in *Baseline demand*, leading to a state-wide average of 2.96 in 2050.

The county-level percent of population living in households is held constant at year 2006 levels in each scenario.

The variation in household characteristics by scenario is described in Table 7.

Table 7. California household projections and assumptions by scenario.

	Maximum demand	Baseline demand Baseline - low efficiency Baseline - high efficiency	Minimum demand
Population (millions)			
2025	48.79 (33%)	45.93 (26%)	40.99 (12%)
2050	70.00 (92%)	54.78 (50%)	44.77 (22%)
Percent single-family households (% SFHH)			
2025	73.1% (6%)	69.0% (0%)	65.7% (-5%)
2050	77.3% (12%)	69.0% (0%)	63.0% (-9%)
Avg. persons-per household (PPH)			
2025	2.83 (-4%)	2.96 (0%)	3.12 (5%)
2050	2.65 (-10%)	2.96 (0%)	3.33 (13%)
Single-family households (millions)			
2025	12.35 (48%)	10.67 (28%)	8.44 (1%)
2050	19.92 (138%)	12.93 (55%)	8.27 (-1%)
Multi-family households (millions)			
2025	4.56 (20%)	4.61 (21%)	4.44 (16%)
2050	5.85 (54%)	5.26 (38%)	4.87 (28%)

* Values in parentheses show the percent increase compared to 2005.

4.3. Gross State Product

Forecasts of California Gross State Product (GSP) by demand scenario are illustrated in Figure 3. The *Baseline demand* scenario assumes an average annual growth rate of 2.75%, equal to the annual average from 1990-2003 (CEC, 2005b), increasing GSP to about $5 trillion in 2050. *Maximum demand* projects an average annual growth rate of 3.73%, equal to the annual average projected through 2016 in IEPR2005, and leading to a year 2050 GSP of $7.7 trillion. And in the *Minimum demand* scenario, GSP is projected to grow at an average annual rate of 1.05%, to $2.3 trillion in 2050.

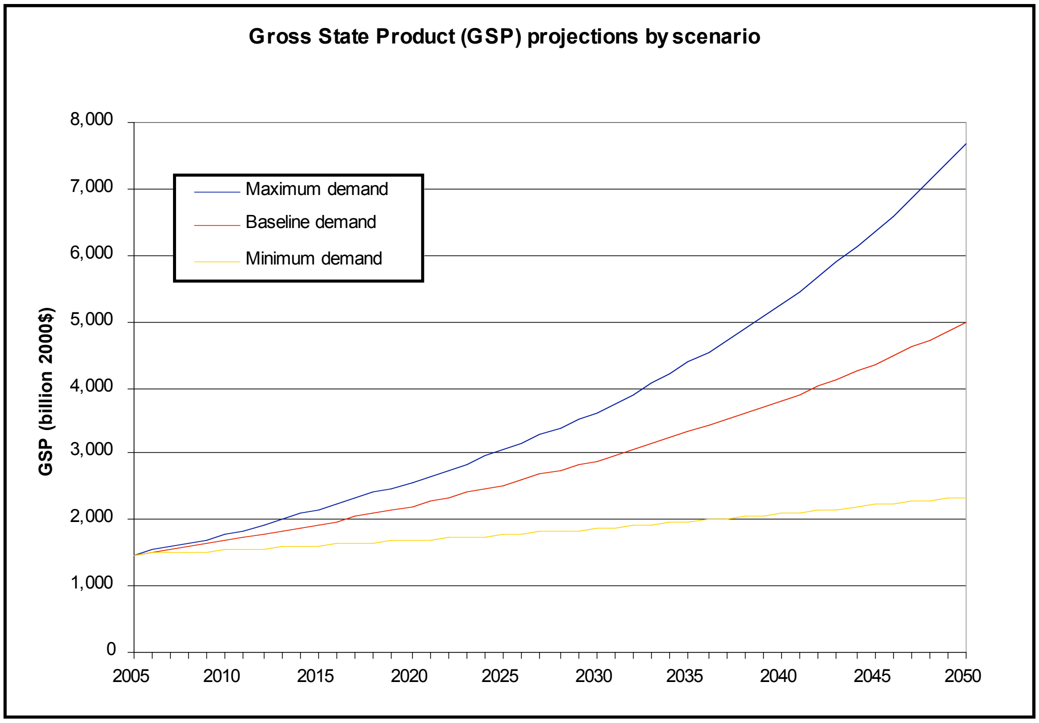


Figure 3 California GSP projections by scenario.

We developed high and low per-capita GSP growth rates based on the *Baseline demand* scenario, and applied them to the scenario population projections to project GSP for *Maximum demand* and *Minimum demand* according to the following equation:

$$GSP_{year} = (\text{GSP per-capita})_{year-1}(1 + \text{GSP per-capita growth rate})_{year}(\text{Population})_{year} \quad (3)$$

Table 8 summarizes the assumptions used in the GSP forecasts.

Table 8. GSP projections and assumptions by scenario.

	Maximum demand	Baseline demand Baseline - low efficiency Baseline - high efficiency	Minimum demand
Avg. annual GSP growth rate	3.73%	2.75%	1.05%
Avg. annual per-capita GSP growth rate	2.25%	1.83%	0.59%
Avg. annual pop. growth rate	1.45%	0.90%	0.45%
Population (millions)			
2025	48.79 (33%)	45.93 (26%)	40.99 (12%)
2050	70.00 (92%)	54.78 (50%)	44.77 (22%)
GSP (billion 2000$)			
2025	$3,050 (107%)	$2,531 (72%)	$1,768 (20%)
2050	$7,683 (422%)	$4,987 (239%)	$2,349 (160%)

* Values in parentheses show the percent increase compared to 2005.

4.4. Commercial floorspace

Building floorspace serves as the primary driver for commercial sector energy use. Figure 4 summarizes California commercial floorspace projections by scenario. Commercial floorspace is projected to reach 10,149 million ft^2 state-wide in 2050 in *Baseline demand*, and 12,969 million ft^2 and 8,295 million ft^2 in *Maximum demand* and *Minimum demand,* respectively.

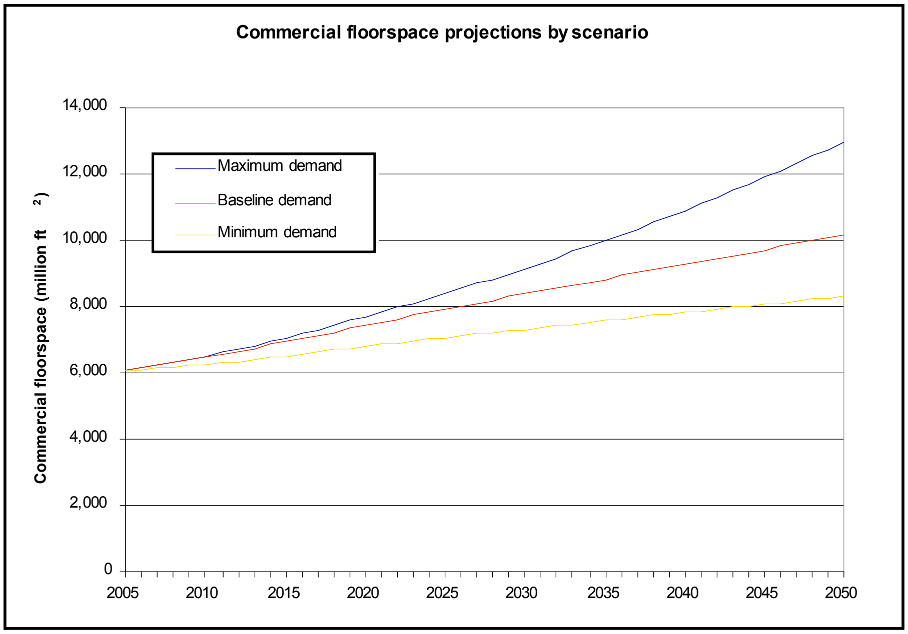


Figure 4 California commercial floorspace projections by scenario.

We project floorspace for 12 building types in the seven electricity planning areas. *Baseline demand* adopts the methods used by the CEC in the IEPR projections (CEC, 2005b), adding the average of annual floorspace additions from 1990-2013 to 99.5% of previous year floorspace (assumes a 0.5% decay rate). Note that for *Baseline demand*, floorspace is not explicitly tied to population growth.

In the alternate scenarios, we scale *Baseline demand* floorspace by state population, as historical floorspace is highly correlated with population (0.998 from 1980-2003). Regional fractions of state floorspace remain constant in each scenario, as population is assumed to occur in the same relative distribution among scenarios (as described in *Section 4.1*).

4.5. Industrial shipments

The primary driver used for modeling energy use in the industrial sector is the value of industrial shipments, which reflects the value of production in an industry. Forecasts for state-wide industrial shipments are illustrated in Figure 5 for each scenario. Our methods, described below, lead to a wide variation in shipment projections across scenarios. Shipments in *Baseline demand* increase from \$589 billion in 2005 to \$1,914 billion in 2050 (in constant 2001\$). *Maximum demand* sees a dramatic increase in shipments to \$3,561 billion in 2050, while *Minimum demand* sees only a very modest increase, to \$726 billion in 2050.

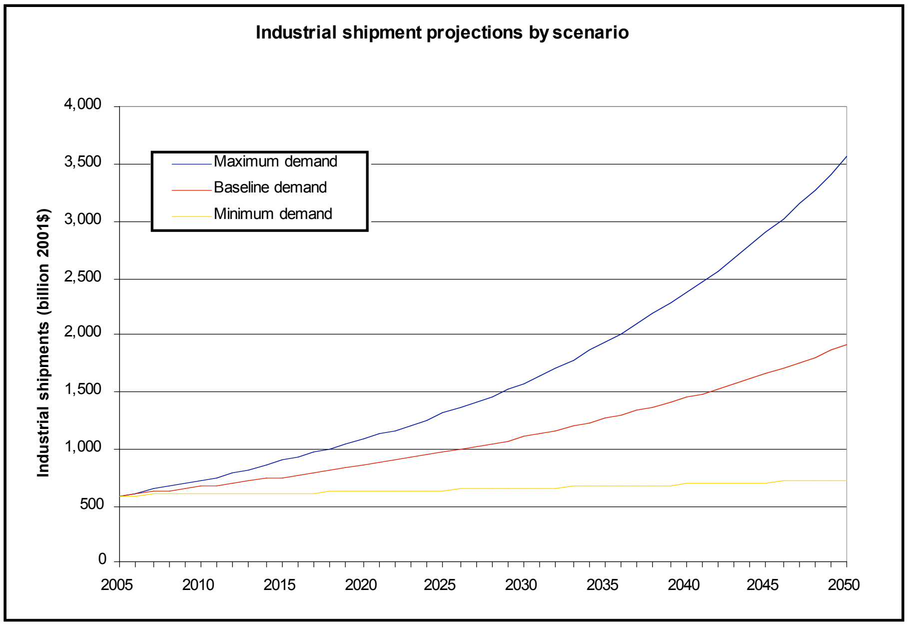


Figure 5 California industrial shipment projections by scenario.

We project shipments in the seven electricity planning areas for 33 industrial sub-sectors according to the Standard Industrial Classification (SIC) coding system.[4] Year 2005 shipments, as projected in IEPR2003, provides the base-year data, and we use average annual growth rates projected for 2003-2016 in IEPR2005 (CEC, 2005b) to project forward.[5] Shipments are allocated regionally according to extrapolated regional projections from IEPR2003 (as projected in the *AEP Baseline Scenario Report*), and regional fractions of state-wide shipments are held constant across scenarios.

Baseline demand shipments reflect a continuation of the projected annual growth rates from IEPR2005. *Minimum demand* and *Maximum demand* scale from these projections according to scenario GSP and shipment fraction of GSP (SFGSP). Specifically, shipments in a given year for a particular SIC code are calculated for an alternate scenario as follows:

$$\text{Shipments}_{\text{alt scenario}} = \left(\text{Shipments}_{\text{baseline}}\right)\left(\frac{\text{GSP}_{\text{alt scenario}}}{\text{GSP}_{\text{Baseline}}}\right)\left(\frac{\text{shipment fraction of GSP}_{\text{alt.scenario}}}{\text{shipment fraction of GSP}_{\text{Baseline}}}\right) \quad (4)$$

The variation of SFGSP in these alternate scenarios amplifies the difference in shipments beyond scenario differences in GSP, and accounts for shifts in the economy towards, or away from, the industrial sector. In *Baseline demand*, SFGSP varies between 36.87% and 38.86%, and is equal to 37.27% in 2050. *Maximum demand* has shipments trending to 45% of GSP by 2050, while industrial shipments decline to 30% of GSP in 2050 in *Minimum demand*.

---

[4] A new coding system, the North American Industry Classification System (NAICS), has replaced the SIC. We project energy use according to SIC code due to the availability of industrial sector energy consumption data in that format.

[5] Data categorized by NAICS code in IEPR2005 was mapped to SIC code for use in the projections according to USCB (2001).

5. ELECTRICITY PROJECTIONS

Electricity is one of the critical areas for California's energy system. Disruptions to California's electricity sector led to rolling blackouts and price escalation in 2000 and 2001. Adequate planning is critical because electricity must be generated and distributed to the point of use at the exact time of use. Especially during summer months, electricity demand can become volatile with large swings in demand due to weather events.

Electricity projections are disaggregated by sector (residential, commercial, industrial, agricultural, and *other*), region (see Table 3), and temporally (hourly). The projections are based upon trends in sector energy intensities, which are scaled to total electricity use by multiplying by relevant demographic and economic parameters described in *Section 0*. Table 9 describes the variables used in the electricity demand projections and the level of disaggregation for each sector.

Table 9. Level of disaggregation and variables used in electricity demand projections.

Sector	Regional disaggregation	Other disaggregation	Activity variables	Sources
Residential	Climate zone (14) Planning areas (7)	End use (18) Household type (2)	End use saturation Unit energy consumption Households	Quantum (2006) DOF (2004) Landis & Reilly (2003) DOF (2006)
Commercial	Planning areas (7)	End use (10) Building type (12)	Floorspace Energy intensity	CEC (2003a) CEC (2005c) USGBC (2005)
Industrial	Planning areas (7)	Industrial classification (33)	Shipments Energy intensity	CEC (2003a) KEMA, 2006 EIA, 2006
Agricultural	Planning areas (8) [a]	Industrial classification (4)	Scaled by GSP	CEC (2003a)
Other	Planning areas (7)	Industrial classification (19)	Scaled by population	CEC (2003a)

[a] An eighth electricity planning area, the Department of Water Resources, is defined only for the agricultural sector.

The input data from the IEPR electricity projections extend to 2016 for the residential sector and 2013 for the *other* sectors. Electricity demand is calculated for each sector, as the sum of disaggregated consumption in terms of end uses, building types, and/or industrial classification. Projections to 2050 are made at the disaggregated level by extending trends in specific industrial size or share, share or saturation of end use, and energy intensity within the subgroups. These projected trends are multiplied by projected activity to determine total energy use for the sector.

5.1. Summary

State-wide electricity demand projections through 2050 are illustrated in Figure 6 for each scenario. In *Baseline demand*, California electricity consumption increases from 271 TWh in 2005 to 421 TWh in 2050. In *Maximum demand*, year 2050 electricity consumption reaches 633

TWh, 63% higher than *Baseline demand*. And in *Minimum demand*, state-wide electricity consumption decreases, to 217 TWh in 2050.

The projections from IEPR2005 are also shown, to 2016. The difference between the IEPR forecast and *Baseline demand* is less than 2%, primarily reflecting differences in activity (particularly households and GSP).

Again, *Maximum demand* and *Minimum demand* present a convergence of reasonable maxima and minima in the underlying assumptions, and presumably bound future consumption, excepting transformational social or policy shifts. It is interesting to note, then, the relatively small deviation among *Baseline - low efficiency*, *Baseline - high efficiency*, and *Baseline demand*. In *Baseline - low efficiency*, electricity consumption reaches 454 TWh in 2050, a 7.6% increase over *Baseline demand*, and in *Baseline - high efficiency*, year 2050 electricity consumption is 357 TWh, 15.3% less than in *Baseline demand*.

Recall that these moderate scenarios couple the (presumed) extreme efficiency assumptions of *Maximum demand* and *Minimum demand* with the demographic and economic assumptions of *Baseline demand*. The results suggest that the range of demographic and economic activity drivers considered in these bounding scenarios far outweigh the effects of large changes in efficiency on future electricity consumption, and that absent a decline in activity, energy efficiency alone is unlikely to result in declining energy consumption in the future.

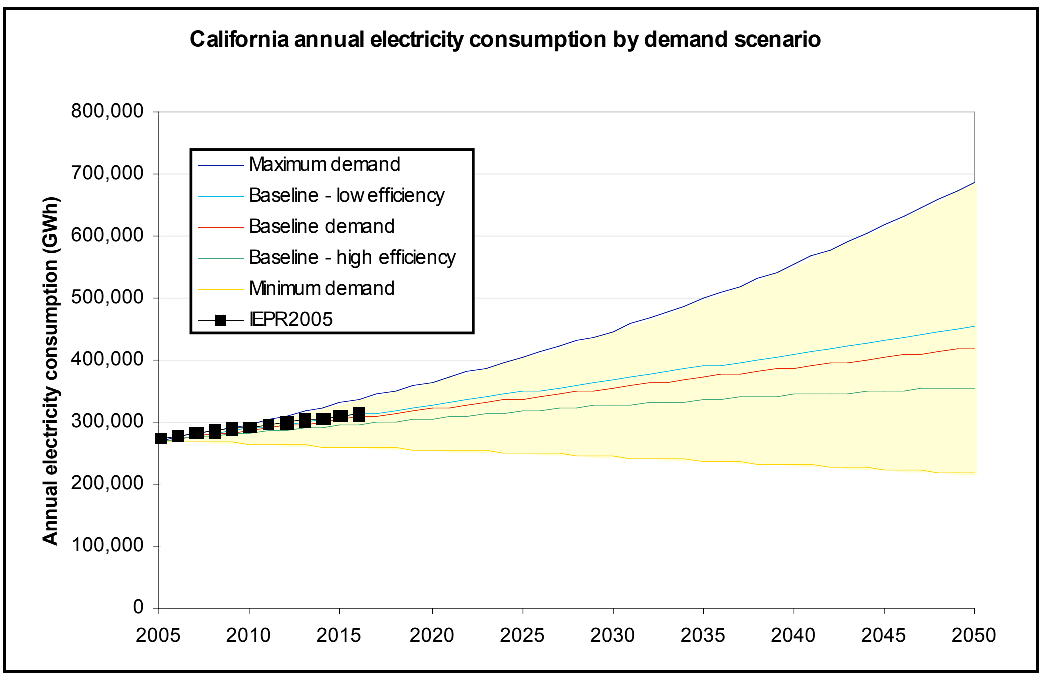


Figure 6 California electricity consumption projections by demand scenario.

The trends seen for annual electricity consumption in the demand scenarios might be clarified by considering per-capita electricity consumption, shown in Figure 7. In the *Baseline demand* scenario, we see that, given our assumptions for each sector, per-capita electricity consumption increases from 7,421 kWh/year in 2005 to 7,694 kWh/year in 2050. This result is somewhat surprising, given the continual efficiency improvements assumed in *Baseline demand*, and reflects the impact of the growth in economic activity that outpaces population growth (1.83% average annual per-capita GSP growth). Given the noticeable increase in efficiency for all types of end uses, the slight increase in per capita electricity consumption reflects an increase in the amount of energy services provided to the consumer. The impact of economic growth is significant, and is the primary driver behind the non-linear growth in consumption seen in *Maximum demand*. It also helps explain increasing consumption projected in *Baseline - high efficiency*, despite the noticeable improvements in efficiency for that scenario.

Per-capita electricity consumption is projected to increase an average of 0.63% annually in *Maximum demand*, to 9,836 kWh/year in 2050, and 0.24% per-year in *Baseline - low efficiency*, to 8,280 kWh/year. *Baseline - high efficiency* and *Minimum demand* see average annual reductions in per-capita electricity consumption of 0.29% and 0.94%, respectively, to 6,514 kWh/year and 4,853 kWh/year in 2050.

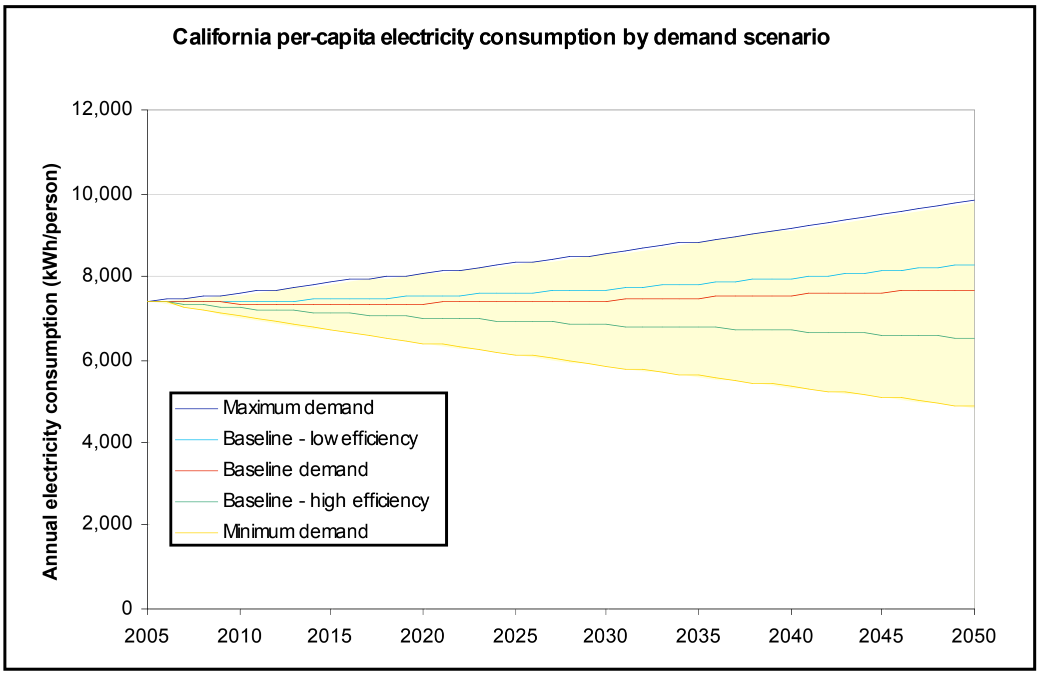


Figure 7 California annual per-capita electricity consumption by demand scenario.

Figure 8 and Figure 9 illustrate the sectoral- and regional-breakdown of electricity consumption for *Baseline demand*. The relative fraction of energy consumption by sector and region is similar for each scenario. The figures illustrate the dominance of the residential and commercial sectors on electricity demand, and that of the PG&E and SCE planning regions. Over two-thirds of total electricity demand is concentrated in the two sectors, while 75% of total electricity demand is concentrated into the two largest investor owned utility planning areas.

The regional fraction of state-wide electricity consumption roughly matches the regional fraction of state-wide population in the PG&E, SCE, and LADWP planning areas. SMUD and SDGE use disproportionately less energy than their population share, largely due to limited industrial sector electricity consumption, while BGP and the *Other* planning areas use more energy than their population share. Relatively high commercial sector and industrial sector energy use leads to a 35% greater share of energy consumption compared to population share in the BGP region. The *Other* region consumes a greater fraction of electricity in each sector than its state-wide population share, leading to a share of total energy consumption that is 119% greater than the region's population share.

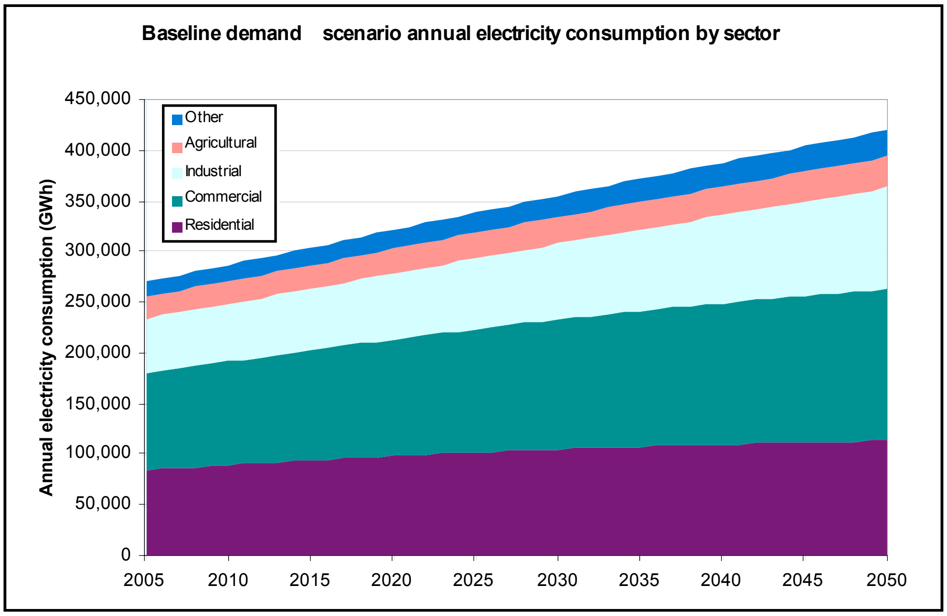


Figure 8 ***Baseline demand*** **scenario electricity consumption by sector.**

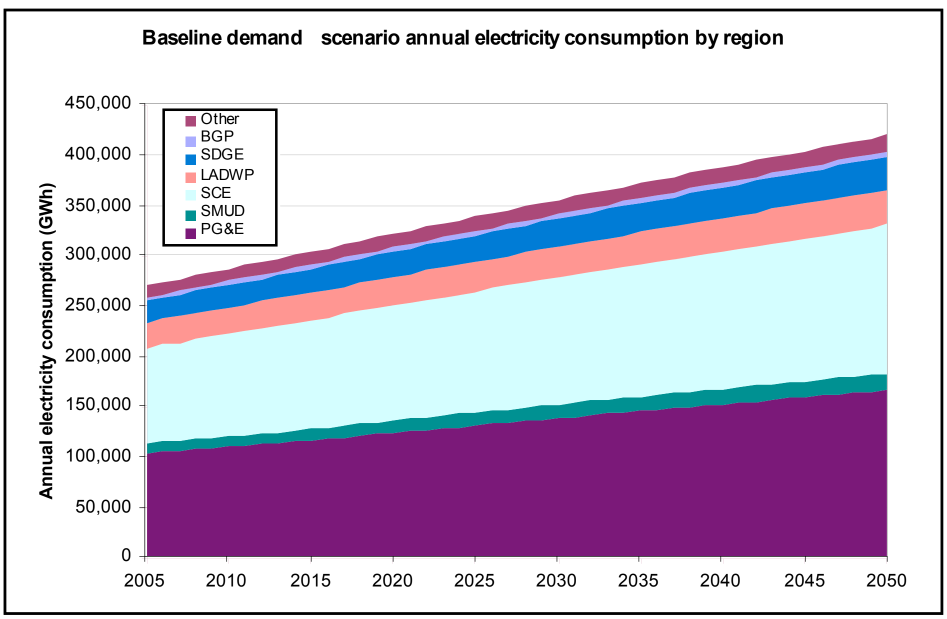


Figure 9 ***Baseline demand*** **scenario regional electricity consumption.**

5.2. Residential sector

5.2.1. Methods and assumptions

Projections for the residential sector are based upon work by Quantum Consulting/Itron for annual residential electricity consumption through 2050 (Quantum Consulting/Itron, 2006). Saturation and unit electricity consumption (UEC) are projected for 18 end uses and two household types (SFHH and MFHH), which are multiplied by the projected number of households and summed across regions to determine state-wide electricity use:

$$\text{Res. elec. use} = \sum_{\text{county}} \begin{pmatrix} \text{Energy for all} \\ \text{SFHH demands} \end{pmatrix} (\text{No. SFHH}) + \sum_{\text{county}} \begin{pmatrix} \text{Energy for all} \\ \text{MFHH demands} \end{pmatrix} (\text{No. MFHH}) \quad (5)$$

Base-year (2006) end use UEC and saturation derive from the CEC's 2006-2016 Demand Forecast (CEC, 2005a), and year 2050 values are projected based upon expected efficiency improvements and market trends. End use UEC and saturation values for years 2007-2049 are determined from linear interpolation.

The 18 electricity end uses included in the modeling are listed in Table 10. Energy intensity variables for end uses relating to heating and cooling are climate zone-specific, while those for the remaining 14 end uses are similar throughout climate zones.

Table 10. Residential electricity demand end uses.

	End use
Not climate-specific	Water heating (WH) Dishwasher WH – Dishwasher Clothes washer WH – Clothes washer Clothes dryer Miscellaneous Cooking Refrigerator Freezer Swimming pool pump Hot tub pump Hot tub heating Lighting
Climate-specific	Space heating Furnace fan Central AC Room AC

Quantum/Itron develops a range of efficiency assumptions that we apply to our scenario demand projections. Our high-efficiency scenarios adopt their "Green dream" UEC projections, while *Baseline demand* uses their "Optimistic" case, and our low-efficiency scenarios assume no improvements beyond a phase-in of current technology.

The assumptions underlying the scenario projections for residential electricity demand are described in Table 11. For simplicity, end use-specific UEC and saturation rates are aggregated into average household energy use. As described above, *Baseline - low efficiency* and *Baseline - high efficiency* adopt the *Baseline* demographic and economic assumptions, and the *Maximum demand* and *Minimum demand* efficiency assumptions, respectively. But the average UEC values vary slightly between *Maximum demand* and *Baseline - low efficiency*, and between *Baseline - high efficiency* and *Minimum demand*, due to the geographical variability in energy consumption and the regional differences in household distribution among scenarios.

Table 11. Residential electricity assumptions and projections.

	Maximum demand	Baseline - low efficiency	Baseline demand	Baseline - high efficiency	Minimum demand
Number of Households (millions)					
Single-family					
2025	12.35 (48%)	10.67 (28%)	10.67 (28%)	10.67 (28%)	8.44 (1%)
2050	19.92 (138%)	12.93 (55%)	12.93 (55%)	12.93 (55%)	8.27 (-1%)
Multi-family					
2025	4.56 (20%)	4.61 (21%)	4.61 (21%)	4.61 (21%)	4.44 (16%)
2050	5.85 (54%)	5.26 (38%)	5.26 (38%)	5.26 (38%)	4.87 (28%)
Energy use per household (kWh/year)					
Single-family					
2025	8,208 (2%)	8,208 (2%)	7,714 (-4%)	6,914 (-14%)	6,807 (-15%)
2050	8,386 (4%)	8,387 (4%)	7,210 (-10%)	5,325 (-34%)	5,155 (-36%)
Multi-family					
2025	4,555 (-1%)	4,565 (0%)	4,313 (-6%)	3,813 (-17%)	3,780 (-18%)
2050	4,510 (-2%)	4,525 (-1%)	3,927 (-14%)	2,745 (-40%)	2,679 (-42%)
Residential electricity demand (TWh)					
2025	122.1 (44%)	108.7 (28%)	102.2 (21%)	91.4 (8%)	74.2 (-12%)
2050	193.4 (128%)	132.3 (56%)	113.9 (34%)	83.3 (-2%)	55.7 (-34%)

* Values in parentheses show the percent increase compared to 2005.

The assumptions upon which Quantum/Itron bases its efficiency projections are not thoroughly documented, but they reflect an extensive review of the literature and interviews with experts. Their "Green Dream" efficiency scenario, used in our *Baseline - high efficiency* and *Minimum demand* scenarios, includes assumptions that would require significant shifts in current policy and market trends, and presumably provides a reasonable boundary for high-end efficiency assumptions. The slight increase in UEC seen in 2025 for the frozen efficiency scenarios reflects a shift in household location to regions with higher energy consumption. In 2050, the complete phase-in of current technologies results in a slight decline in UEC, to the marginal value of year 2006 technology.

5.2.2. Results

The scenario projections for residential electricity consumption in the State are depicted in Figure 10. *Baseline demand* foresees a 34% increase in energy consumption compared to 2005 values, to 114 TWh in 2050. *Maximum demand* and *Minimum demand* see and increase of 128% (to 193 TWh in 2050) and a decrease of 34% (to 56 TWh in 2050), respectively. Demand in *Baseline – low efficiency* increases to 132 TWh in 2050, 56% higher than in 2005. And in

Baseline - high efficiency, consumption in 2050 is 2% below that of 2005, after peaking at 91 TWh in 2027.

Energy consumption in 2016 according to the IEPR projections is 9% greater than our *Baseline demand* scenario. The difference is attributable to aggregation of end uses in the Quantum/Itron projections, compared to IEPR, and to simplifications we made in interpolating UEC between 2050 and current values.

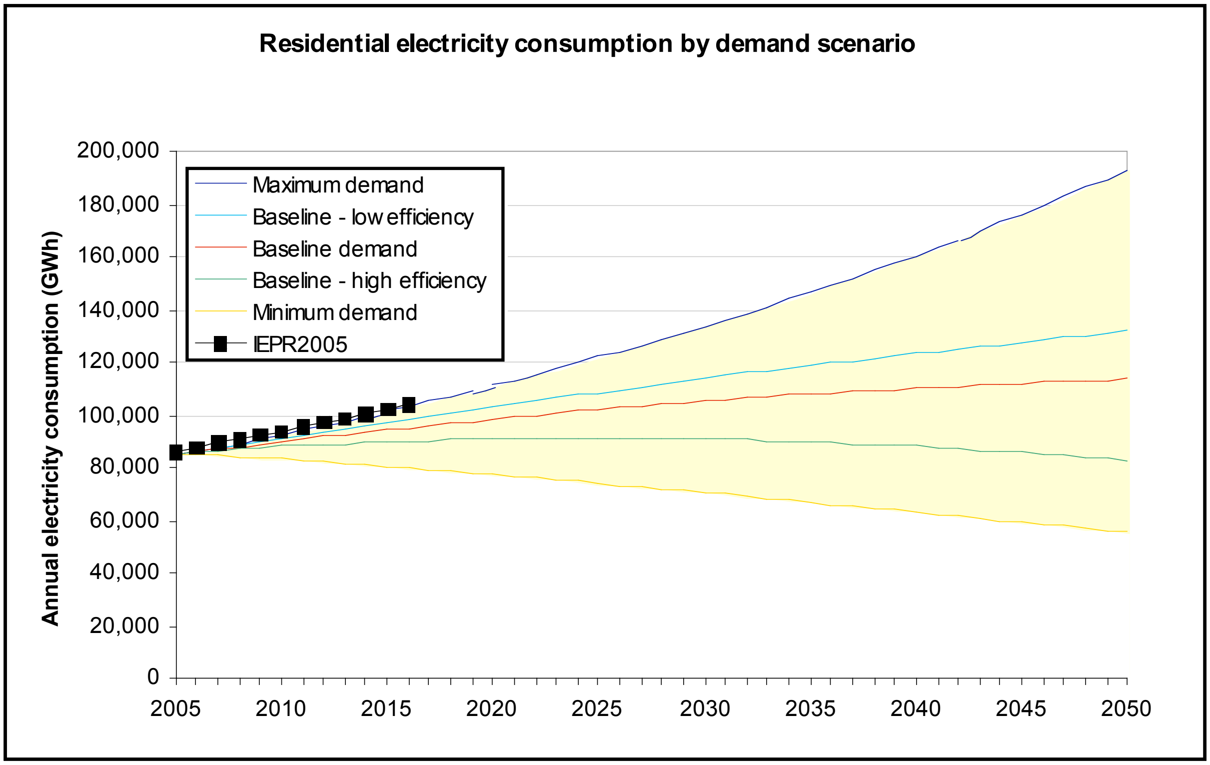


Figure 10 California residential electricity consumption by demand scenario.

The flattening (or declining) demand projections seen in the latter decades of each scenario except *Maximum demand* reflect declining population growth rates. In *Maximum demand*, population is assumed to grow constantly at 1.45% per-year, and consequently, demand grows at a relatively constant rate, as well (1.85% per-year).

The impact of activity (i.e., number of households) on electricity consumption is evident by comparing Figure 10 and Table 11. For example, in *Maximum demand*, despite slightly improving efficiency, energy consumption increases 128%, due to an increase of 112% in the total number of households and a shift towards SFHH. And in *Baseline - high efficiency*, a 49% increase in households essentially negates projected efficiency improvements. *Minimum demand* offers a glimpse at the effect of energy efficiency improvements alone. The 8% increase in total households is somewhat offset by the shift towards MFHH, and the resulting 34% decline in energy consumption more-closely reflects projected UEC (36% for SFHH and 42% for MFHH) than for the other scenarios.

5.3. Commercial sector

5.3.1. Methods and assumptions

Commercial projections are disaggregated into 10 end uses for each of 12 building types. Those included in the projections are listed in Table 12. Energy use intensity (EUI) is defined at the end use level in each building type, in terms of annual energy consumption per square foot of floorspace. Scenario floorspace is projected as described in *Section 4.4*, and annual end use electricity consumption is defined as the product of the two. The sum of energy consumption across all end uses, building types, and regions yields sector-wide consumption, as follows:

$$\text{Comm. elec. use} = \sum_{region}\left(\sum_{\substack{building\\type}}\begin{pmatrix}\text{Building}\\\text{floorspace}\end{pmatrix}_{\substack{buildingtype,\\region}} \cdot \left(\sum_{enduse}\begin{pmatrix}\text{Energy use}\\\text{per ft}^2\end{pmatrix}_{\substack{enduse,\\buildingtype,\\region}}\right)\right) \quad (6)$$

Table 12. Building types and end uses in the commercial sector electricity projections.

Building types	End uses
Colleges	Cooling
Food stores	Heating
Hospitals	Ventilation
Hotel/Motel	Water heating
Large Offices	Cooking
Miscellaneous	Refrigeration
Refrigerated warehouses	Indoor lighting
Restaurants	Outdoor lighting
Retail stores	Office equipment
Schools	Miscellaneous
Small Offices	
Warehouses	

We define three efficiency scenarios using data from IEPR2003 to project maximum, baseline, and minimum EUI. *Maximum demand* (and *Baseline - low efficiency*) freezes EUI at projected year 2005 values, based upon the CEC's 2003-2013 demand forecast (CEC, 2003a). *Baseline demand* takes the minimum of the extrapolated CEC projections and the frozen efficiency case for each end use within each building type. That is, end use EUI is not allowed to increase compared to projected 2005 values. In cases where it is projected to decrease, it is assumed to do so exponentially, based on average annual percentage growth rate from 2003-2013. Finally, the high efficiency scenario assumes that EUI declines by 15% in 2015 compared to current values, and that all floorspace added after 2015 uses 40% less electricity (compared to current values). These assumptions apply to *Minimum demand* and *Baseline - high efficiency.* The 15% reduction by 2015 assumes that all technically feasible efficiency improvements are made to existing buildings by 2015 (CEC, 2005c). Beyond that, the high efficiency scenario assumes that all new buildings are LEED-certified Platinum, which we assume consume 40% less energy than existing buildings (USGBC, 2005). These assumptions are quite optimistic, and presumably bound the lower end of the EUI parameter space.

The assumptions used in the commercial electricity projections, and the resulting forecasts are listed in Table 13. For simplicity, floorspace is summed across all building types and EUI is presented as an average value for all end uses and building types. It is apparent that the efficiency assumptions for *Baseline demand* lead to rather small reductions in EUI. Simply extrapolating EUI from the CEC 2003-2013 forecast actually led to *increasing* EUI, and a worse case scenario than captured in our *Maximum demand* case (although increasing EUI is certainly feasible, we bound efficiency assumptions for each sector with the frozen case). Thus, our forecast method for the baseline EUI only finds a small reduction by 2050.

Table 13. Commercial electricity assumptions and projections.

	Maximum demand	Baseline - low efficiency	Baseline demand	Baseline - high efficiency	Minimum demand
Population (millions)					
2025	48.79 (33%)	45.93 (26%)	45.93 (26%)	45.93 (26%)	40.99 (12%)
2050	70.00 (92%)	54.78 (50%)	54.78 (50%)	54.78 (50%)	44.77 (22%)
Floorspace/person (ft^2)					
2025	172.3 (4%)	172.3 (4%)	172.3 (4%)	172.3 (4%)	172.3 (4%)
2050	185.3 (12%)	185.3 (12%)	185.3 (12%)	185.3 (12%)	185.3 (12%)
Floorspace (million ft^2)					
2025	8,408 (38%)	7,915 (30%)	7,915 (30%)	7,915 (30%)	7,063 (16%)
2050	12,969 (114%)	10,149 (67%)	10,149 (67%)	10,149 (67%)	8,295 (37%)
Avg. energy intensity ($kWh/ft^2/year$)					
2025	15.94 (0%)	15.94 (0%)	15.43 (-3%)	13.77 (-13%)	13.77 (-13%)
2050	15.98 (1%)	15.98 (1%)	14.81 (-7%)	11.08 (-30%)	11.08 (-30%)
Commercial sector electricity demand (TWh)					
2025	134.1 (39%)	126.2 (31%)	122.1 (27%)	109.0 (13%)	97.3 (1%)
2050	207.2 (115%)	162.2 (68%)	150.3 (56%)	112.4 (17%)	91.9 (-5%)

* Values in parentheses show the percent increase compared to 2005.

5.3.2. Results

Figure 11 illustrates the demand scenario projections for the commercial sector. *Baseline demand* sees a 56% increase in energy demand by 2050, to 150 TWh. Energy consumption more than doubles in the maximum case, and declines slightly (by 5% compared to year 2005 values) in *Minimum demand.* The IEPR2005 projections are within 2% of *Baseline demand* in 2016.

Interestingly, *Baseline - low efficiency* only results in an 8% increase in year 2050 energy use compared to *Baseline demand*, while *Baseline - high efficiency* results in a 25% decline compared to the baseline. This is an effect of the relatively small improvement in baseline EUI compared to the aggressive improvements modeled in the high efficiency cases. The difference between *Baseline demand* and *Maximum demand*, then, is almost entirely due to the underlying floorspace projections, reflecting variable population forecasts.

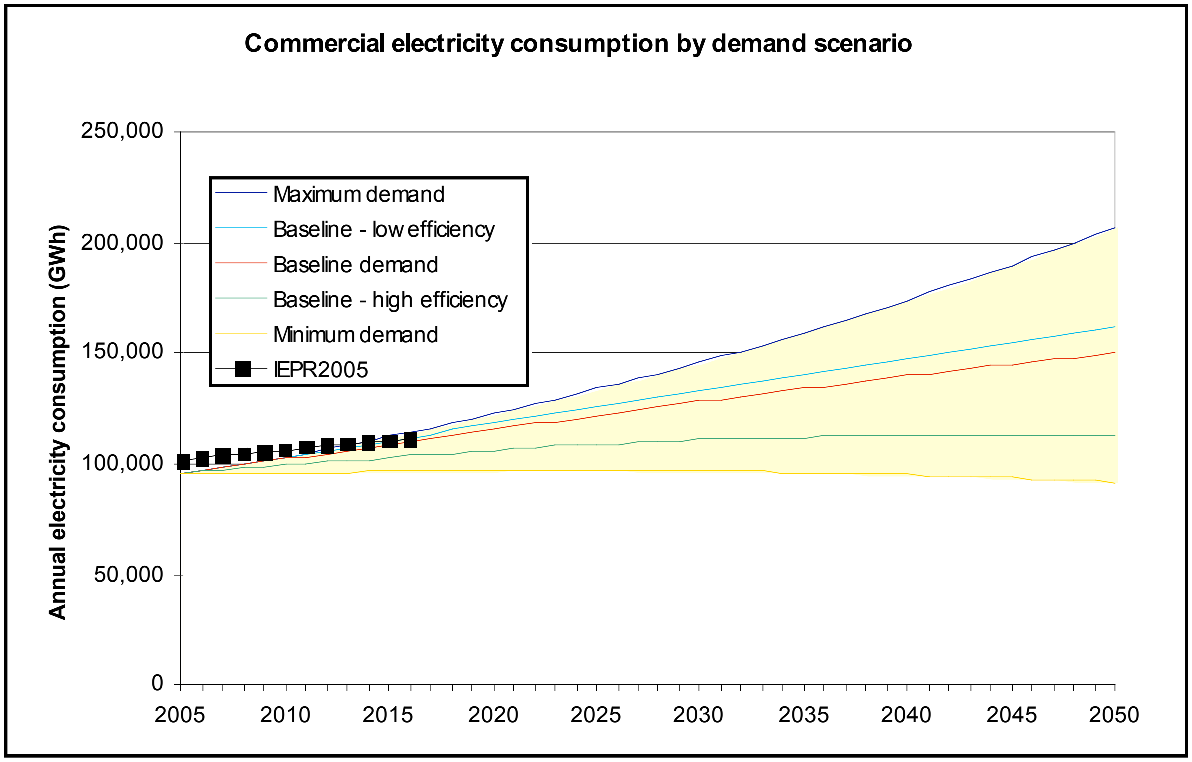


Figure 11 California commercial sector electricity consumption by demand scenario.

5.4. Industrial sector

5.4.1. Methods and assumptions

We project electricity consumption in the industrial sector for 33 industrial classification groups (including mining) and seven utility planning regions, based on data from the 2003-2013 Demand Forecast (CEC, 2003a). Energy consumption is defined as the product of EUI (kWh/2001$ shipped) and shipments (2001$) for each sub-sector and region. State-wide electricity consumption is defined as the sum of the product of these parameters across sub-sectors and regions, as follows:

$$\text{Industrial electricity use} = \sum_{\text{region}} \sum_{\text{sub-sector}} \begin{pmatrix} \text{Energy use per} \\ \text{dollar shipped} \end{pmatrix}_{\substack{\text{sub-sector,} \\ \text{region}}} \begin{pmatrix} \text{Value of} \\ \text{shipments} \end{pmatrix}_{\substack{\text{sub-sector,} \\ \text{region}}} \qquad (7)$$

The industrial sub-sectors included in the model are listed in Table 14, along with their SIC code.

We develop three efficiency scenarios, based on feasible near-term improvements from (KEMA, 2006) and long-term scenarios from the EIA's Annual Energy Outlook (EIA, 2006). The KEMA report considers six efficiency cases through 2016, based on various efficiency program funding levels. We use three to project year 2016 EUI by SIC code: "Naturally occurring" for *Maximum demand* and *Baseline - low efficiency*, "Baseline achievable" for *Baseline demand*, and "Technically achievable" for *Baseline - high efficiency* and *Minimum demand.* These reflect the lowest, second lowest, and highest efficiency assumptions included in the study, respectively.

Table 14. Industry sub-sectors and SIC codes included in industrial sector demand modeling.

Mining	Manufacturing	
Metal mining (10)	Canning, freezing, drying (203)	Misc. plastics (308)
Oil & gas extraction (13)	Sugar (206)	Rubber products (30x)
Nonmetallic materials mining (14)	Food residual (20x)	Leather products (31)
Construction (15)	Textile mill products (22)	Flat glass (321)
	Apparel (23)	Cement (324)
	Wood products (24)	Cement & glass residual (32x)
	Furniture & fixtures (25)	Primary metals (33)
	Pulp mills (262)	Fabricated metal products (34)
	Paper mills (262)	Computer & office equip. (357)
	Pulp & paper residual (26x)	Industry machinery (35x)
	Printing & publishing (27)	Communications equip. (366)
	Chemicals (28)	Electronic components (367)
	Petroleum refining (29)	Remainder of electronics (36x)
		Transportation equip. (37)
		Instruments (38)
		Misc. manufacturing (39)

Beyond 2017, we apply scenario efficiency assumptions from AEO2006. *Baseline demand* adopts the reference case assumption that EUI declines by 1.2% annually. Our maximum and minimum efficiency scenarios use the AEO "Low-tech" and "High-tech" scenarios, respectively, which assume 0.9% and 1.4% annual reductions in EUI. We apply these growth rates uniformly across sub-sectors from 2017-2050.

It should be noted that using the AEO projections might underestimate efficiency potential in California. For example, the "Naturally occurring" and "Baseline achievable" efficiency scenarios from KEMA (2006) project an annual average improvement in EUI of roughly 1.3% (suggesting that the baseline funding scenario leads to little difference in efficiency improvements beyond that driven by normal market forces). And the "Technically achievable" scenario results in an average annual improvement of 1.8%. In each case, the AEO projected growth rate is less (in magnitude) than that projected in the near term for California.

The assumptions used to project industrial sector electricity consumption are presented in Table 15. As for the *other* sectors, the disaggregated values are not shown for simplicity. Rather, state-wide shipments and average EUI values for the entire industrial sector are given. Efficiency is projected to improve noticeably in all scenarios, but exponential increases in shipments in each of the scenarios but *Minimum demand* negate the effect of the improvements on sector energy consumption.

Table 15. Industrial sector electricity assumptions and projections.

	Maximum demand	Baseline - low efficiency	Baseline demand	Baseline - high efficiency	Minimum demand
Shipments (million 2001$)					
2025	1,307 (122%)	967 (64%)	967 (64%)	967 (64%)	636 (8%)
2050	3,561 (505%)	1,914 (225%)	1,914 (225%)	1,914 (225%)	726 (23%)
Avg. energy intensity (kWh/2001$)					
2025	0.075 (-18%)	0.075 (-18%)	0.072 (-21%)	0.070 (-24%)	0.070 (-24%)
2050	0.058 (-36%)	0.058 (-36%)	0.052 (-43%)	0.046 (-49%)	0.046 (-49%)
Industrial electricity demand (TWh)					
2025	97.7 (81%)	72.3 (34%)	69.8 (30%)	67.2 (25%)	44.2 (-18%)
2050	207.1 (284%)	111.3 (107%)	100.2 (86%)	88.9 (65%)	33.7 (-37%)

* Values in parentheses show the percent increase compared to 2005.

5.4.2. Results

Industrial sector electricity consumption projections by demand scenario are illustrated in Figure 12. *Baseline demand* projects an 86% increase in industrial sector energy consumption by 2050, to 100 TWh. Year 2050 energy consumption is twice the baseline in *Maximum demand* and 66% less in *Minimum demand. Baseline – low efficiency* and *Baseline – high efficiency* forecast energy consumption that is 11% above and below the baseline in 2050, respectively. The IEPR2005 projections are 9% less than *Baseline demand* in 2016.

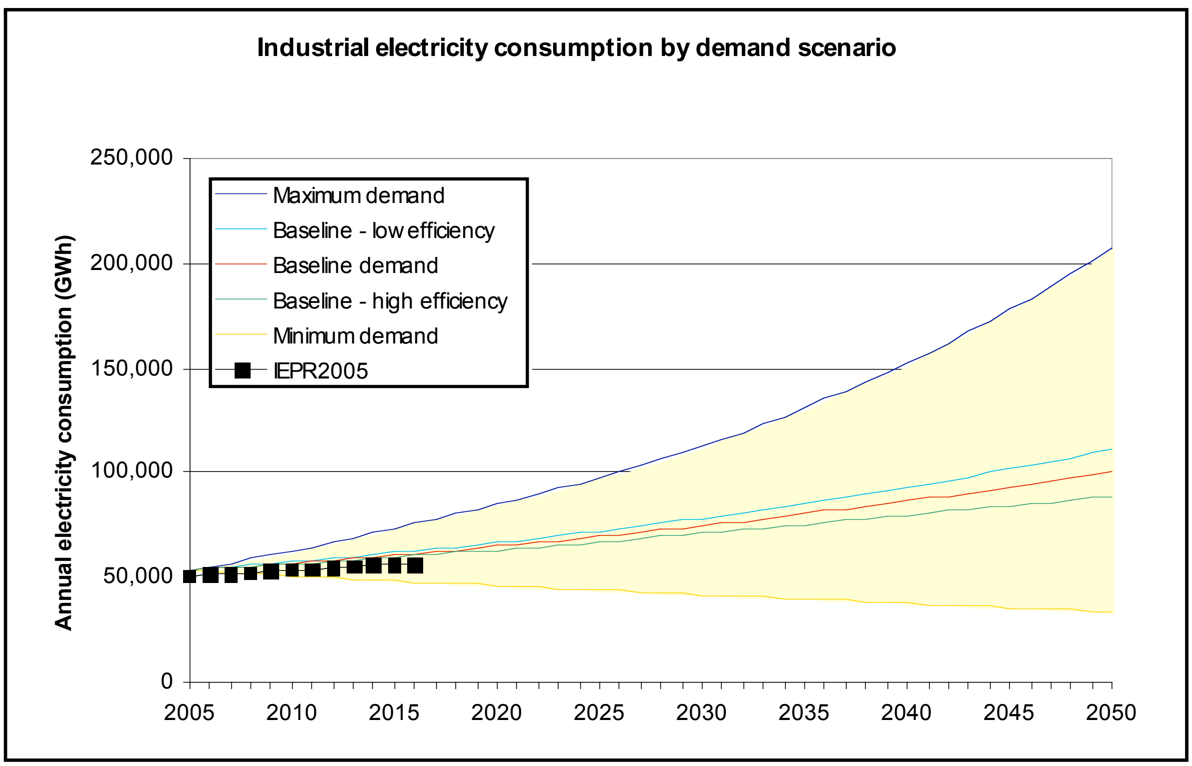


Figure 12 California industrial sector electricity consumption by demand scenario.

The methods described here lead to a very wide range of energy forecasts for the industrial sector. The effect of the efficiency assumptions is relatively small, bounding the *Baseline demand* scenario by ±11%. But the shipment projections lead to a noticeable variation, and are the primary driver behind to the wide range between *Maximum demand* and *Minimum demand*.

Although an almost quadrupling of sector energy consumption as modeled for *Maximum demand* might be unlikely, the assumptions that led to the projection seem reasonable on the boundary. Recall that shipments are scaled from the baseline case by scenario GSP and the fraction of GSP accounted for by shipments. In *Maximum demand*, GSP is expected to grow at an average annual rate of 3.73% through 2050, equal to the average annual growth rate projected through 2016 in IEPR2005. The growth in shipments is then amplified by an increase in SFGSP to 45% in 2050 (compared to 37.3% in *Baseline demand*), which is actually less than what it was in recent years (as high as 50% in 2000). Again, we do not intend to postulate the likelihood of our demand scenarios, but the assumptions underlying the projection seem valid to establish *Maximum demand* as a boundary for industrial electricity consumption.

5.5. Agricultural & *other* sectors

5.5.1. Methods and assumptions

The agriculture and *other* sectors are divided into four and 19 industrial classes, respectively. These are listed in Table 16 with the associated SIC codes.

Table 16. Industry sub-sectors and SIC codes included in agricultural and *other* sector modeling.

Agricultural sector	*Other* sectors
Crops (01)	Streetlighting (0)
Animals (02)	Railroads (40)
Water supply (494)	Local transit (411)
Irrigation (497)	Cabs, other transit (412-417)
	Trucking (421-423)
	USPS (43)
	Water freight (441-445)
	Other water transport (446)
	Air transport (451-452)
	Airports (458)
	Pipelines, except NG (46)
	Transport services (47)
	Telephones (481)
	Telegraphs (482)
	Radio & TV (483)
	Other communication services (489)
	Electric and NG utilities (491-493)
	Sewers (495)
	Nat'l security and international affairs (97)

Due to a lack of shipments or employment data for agriculture and the *other* sectors, energy consumption is projected through 2050 based on projected near-term trends in annual electricity consumption. Projections are disaggregated regionally for each sub-sector, based on the electricity utility planning areas. For the agricultural sector, an eighth planning area is added, the Department of Water Resources, to account for water supply in the agricultural sector.

In *Baseline demand*, energy consumption is projected through 2050 using the linear trend from the IEPR2003 projections for 2003-2013 if energy consumption in an industrial group is growing, and using an exponential decay based on annual growth rates if energy consumption in the group is declining. For the alternate scenarios, agricultural energy consumption is scaled by GSP, and *other* sector energy consumption is scaled by population. Thus, the difference in energy consumption for these two sectors is solely accounted for by demographic and economic factors (i.e., efficiency potential is not taken into account), and projections for the moderate scenarios equal those for *Baseline demand.*

5.5.2. Results

Figure 13 and Figure 14 illustrate the agricultural sector electricity consumption projections and the *other* sector electricity consumption projections, respectively. *Baseline demand* (as well as the moderate scenarios) projects an increase in agricultural electricity consumption of 43% by 2050, to 30.5 TWh. In *Maximum demand*, energy consumption reaches 47.0 TWh in 2050, 121% higher than in 2005, and in *Minimum demand*, agricultural energy consumption drops 33% relative to 2005, to 14.4 TWh.

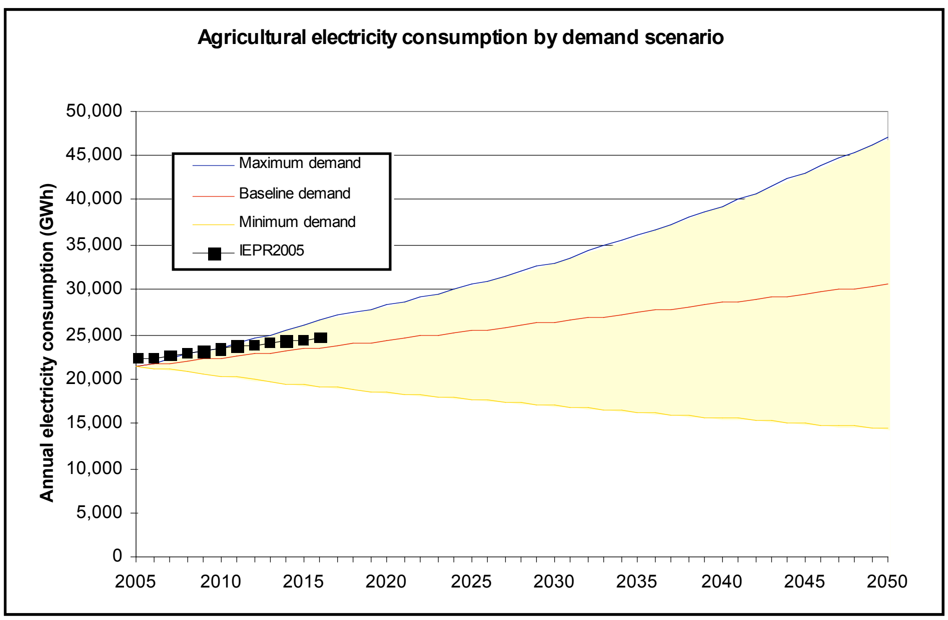


Figure 13 California agricultural sector electricity consumption by demand scenario.

Regarding *other* sector electricity consumption, the *Baseline demand* scenario sees a 77% increase in electricity consumption by 2050, to 26.4 TWh. In *Maximum demand*, energy consumption reaches 33.8 TWh (126% greater than year 2005 demand), and in *Minimum demand*, energy consumption increases to 21.6 TWh in 2050 (a 45% increase).

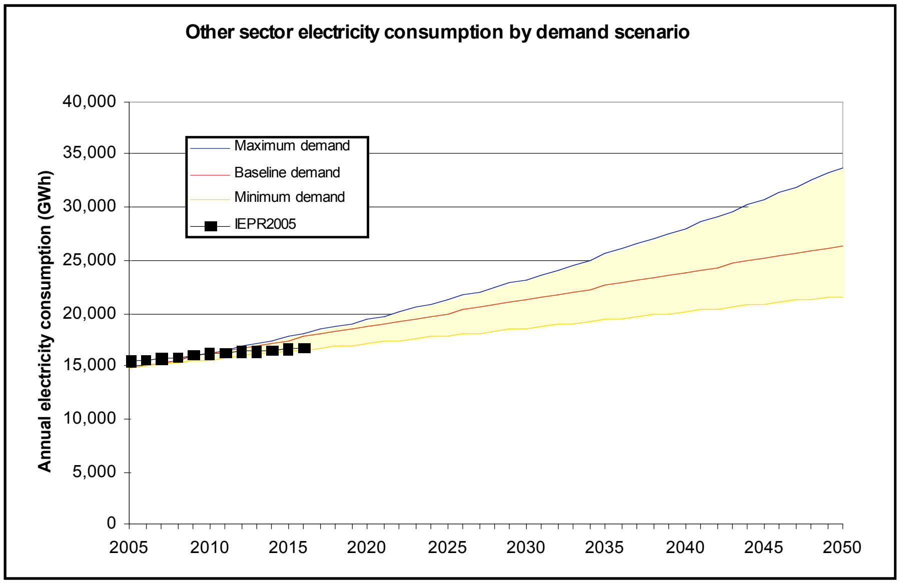


Figure 14 California *other* sector electricity consumption by demand scenario.

Again, the influence of the demographic and economic drivers is apparent in these graphs. For the agricultural sector, where demand is scaled by GSP, there is a wide range of demand projections that reflects our range of GSP forecasts. For the *other* sector, the maximum and minimum scenarios more tightly bound *Baseline demand*, reflecting the smaller variability in our population forecasts. No decrease in demand is projected for *Minimum demand* in the *other* sector due to the fact that we do not forecast a decrease in population.

5.6. Peak and hourly demand projections

5.6.1. Methods and assumptions

Peak and hourly demand projections are derived from an hourly demand profile for California from 2003. This profile is subdivided by sector and utility planning area and is assumed to be representative of an hourly profile for any forecast year.[6] Given annual energy consumption by sector or planning area, we scale the hourly profile to provide peak annual demand and a load duration curve or hourly profile for all 8,760 hours of a particular year.

The representative load duration curves used in this analysis are illustrated in Figure 15. The curves depict the number of hours per year during which load is above a certain fraction of the annual peak-hour demand.

The shape of the curve and the load factor (i.e., the average percent of peak demand) significantly impact the structure and operation of the electricity system. It is apparent from the figure that each sector has a different curve and load factor. The variance stems from variable types of demand. For example, in the residential, commercial, and agricultural sectors, demand varies noticeably with time-of-day and season, reflecting heating and cooling demands and

[6] We do not have hourly demand profiles for the BGP and *Other* planning areas. For those, we use state-wide demand profiles defined as the sum of demands from the other five utilities.

growing seasons. Consequently, load duration curves for those sectors are relatively steep, and their load factors are relatively low (46%-56%). Demand in the industrial and *other* sectors are less time- and season-dependent, leading to flatter curves and higher load factors (69%-76%). The overall load duration curve falls in between, and has a load factor of 60%.

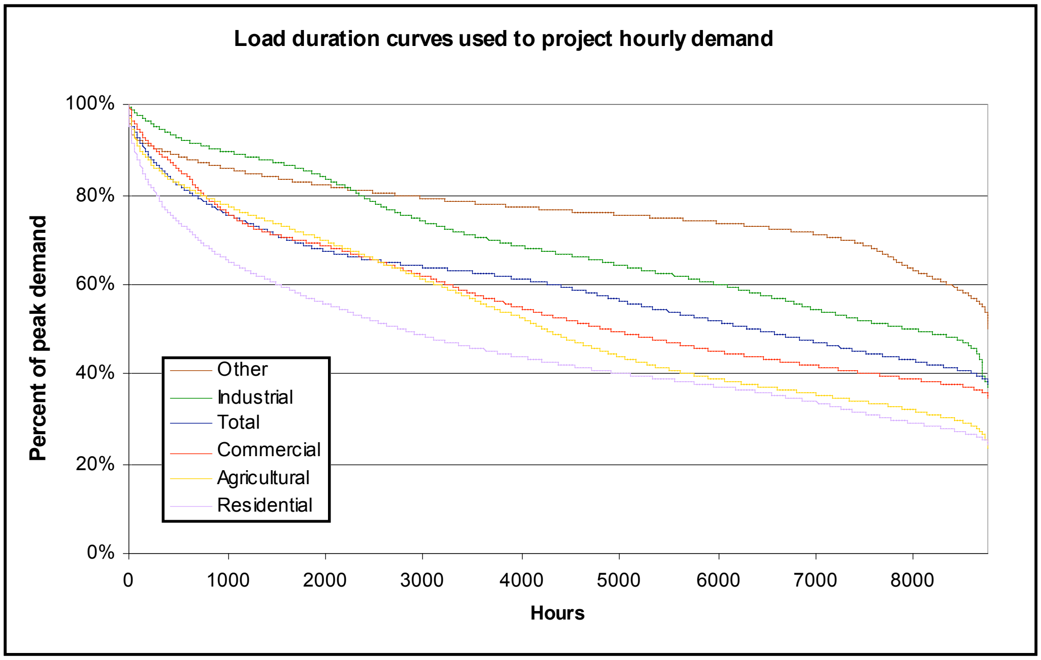


Figure 15 Load duration curves by sector used to project hourly demand.

5.6.2. Results

The scenario projections for annual peak-hour electricity demand are illustrated in Figure 16. In *Baseline demand,* peak-hour demand is projected to increase 53% relative to 2005 values in 2050, to 77.9 GW. Peak demand increases 60% beyond the baseline in *Maximum demand*, and declines 48% relative to the baseline in *Minimum demand*. *Baseline - high efficiency* is 14% below the baseline in 2050, and *Baseline - low efficiency* is 10% greater.

Peak electricity demands are important to planning, as they dictate the size and composition of the electricity sector. Air conditioning drives peak demand, and although it only makes up 5-6% of energy demand for the year, it is concentrated in specific climate zones and during summer daytime hours, leading to disproportionately high demands under those situations. Based on our load curve, peak demand occurs on August 24th at 4:00 PM.

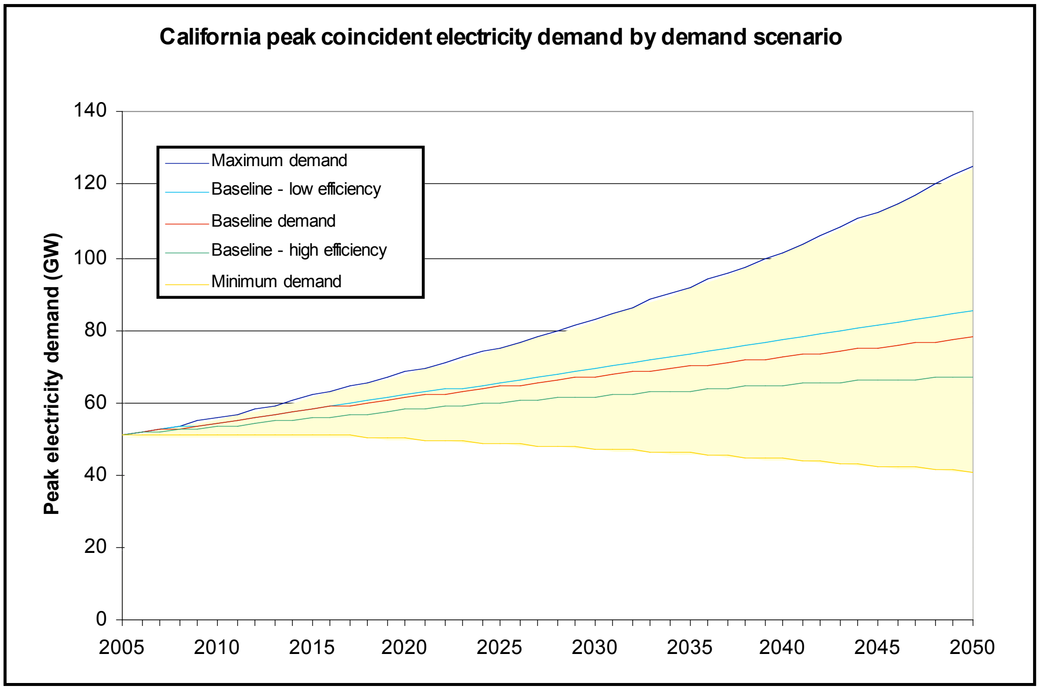


Figure 16 California peak-hour electricity demand by scenario.

An example of hourly electricity demand is illustrated in Figure 17, for *Baseline demand*, during the week of October 30th, 2006. We reiterate that the hourly projections are based on a historical load curve that is directly applied to annual energy consumption projections. We do not adjust the load curve according to the calendar. Consequently, it appears that November 1st is modeled as a Saturday, despite the fact that it falls on a Wednesday in 2006.

Looking at October 30th (presumably a Thursday), we notice several sectoral trends. The residential sector sees two daily demand peaks, one around 8:00 AM, and a larger one around 7:00 PM. In the commercial sector, demand is highest (and relatively constant) during normal business hours, from 9:00 AM to 6:00 PM, and peaks around noon. Demand in the industrial sector increases steadily from 3:00 AM until 11:00 AM, then falls continuously throughout the rest of the day. And demand peaks at 10:00 AM in the agricultural sector, and at 7:00 PM in the *other* sector. Demand peaks at 7:00 PM state-wide.

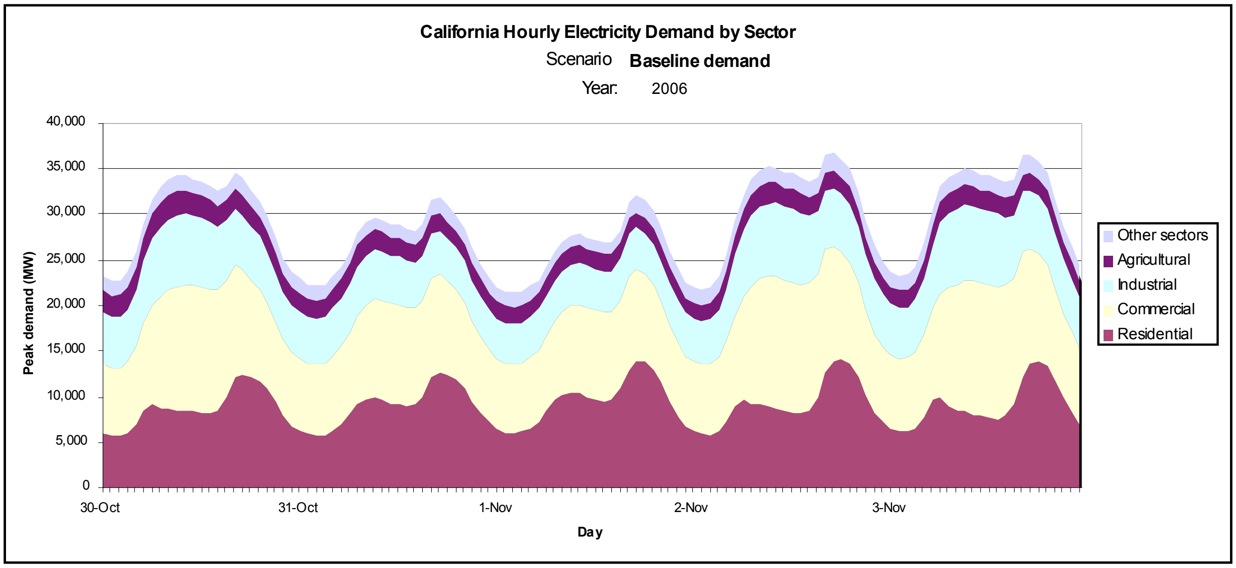


Figure 17 ***Baseline demand*** **hourly electricity demands for the week of October 30th, 2006.**

The hourly profile is critical for understanding the temporal distribution of demand and electricity generation requirements. The extent of the peaks in demand, which can be visualized by the load duration curve and hourly profile, dictates the types of plants required for generating electricity, and ultimately, the cost of electricity to the consumer and the emissions associated with its generation. Eliminating the peaks and leveling the load profile is attractive from an economics standpoint, and using electricity to supply transportation energy requirements could potentially help do so. It could also exacerbate the issue, however, if electric cars are recharged at work, during daytime hours, for example.

Adding hourly electricity demand associated with transportation fueling scenarios is a point for future work. But the hourly demand profile developed in this work helps us visualize scenarios that would lead to best and worst cases.

6. NATURAL GAS

Natural gas is a critical primary energy resource in the state, given its key contribution to electricity generation and its use as a residential, commercial and industrial fuel. Demand has been rising in California and this trend is expected to continue into the future. Recent high prices, uncertain supply, and growing dependence on imports, including liquefied natural gas (LNG), are critical issues for the state. We project natural gas demands in the residential, commercial, industrial, agricultural and *other* sectors. We do not include natural gas demand associated with electricity generation, as it will be an important output of the energy system modeling.

The methods used to project natural gas demand are similar to those used in the electricity forecast, where possible. But in many cases, data regarding historical and projected near-term consumption lack the level of disaggregation that exists for electricity. Consequently, projection methods for some sectors differ for natural gas as compared to electricity. Natural gas projections for the residential sector follow similar methods as for the electricity forecast, including the same level of disaggregation, but derive from data in the 2003-2013 Demand Forecast, rather than the 2006-2016 Forecast. Commercial natural gas demand is projected using the same floorspace projections from the electricity forecast, but lacks disaggregation by building type and end use. Projections for the industrial, agricultural, and *other* sectors lack any disaggregation beyond the regional level, due to lacking data regarding natural gas consumption by industrial classification.

Natural gas demands are forecast for the four natural gas utility planning areas, outlined in Table 17. All the forecasts derive from the 2003-2013 Demand Forecast (CEC, 2003a), with the exception of the household projections, which follow the methodology described for the residential electricity projections. After projecting annual natural gas demands by sector, seasonal demands are forecast on a monthly basis based on historical data from the Energy Information Administration (EIA).

Table 17. Level of disaggregation and variables used in natural gas demand projections.

Sector	**Regional disaggregation**	**Other disaggregation**	**Activity variables**	**Sources**
Residential	Planning areas (3)	End use (12) Household type (2)	End use saturation Unit energy consumption Households	CEC (2003a) CEC (2005c) DOF (2004) Landis & Reilly (2003) DOF (2006)
Commercial	Planning areas (4)	None	Floorspace Energy intensity	CEC (2003a) CEC (2005c) USGBC (2005)
Industrial	Planning areas (4)	Industrial classification (33)	Shipments Energy intensity	CEC (2003a) Itron et al (2006) EIA (2006)
Agricultural	Planning areas (4)	None	Scaled by GSP	CEC (2003a)
Other	Planning areas (4)	None	Scaled by population	CEC (2003a)

6.1. Summary

Figure 18 illustrates the state-wide natural gas consumption projections by demand scenario. In the *Baseline demand* scenario, annual energy demand is projected to increase 39% (relative to 2005 values) by 2050, to about 20,000 MM therms. Year 2050 natural gas consumption is 87% greater than *Baseline demand* in *Maximum demand*, and 56% less in *Minimum demand.* The moderate scenarios project consumption that is 15% greater than *Baseline demand* and 20% less. The IEPR2005 projections are about 5% below *Baseline demand* from 2005-2016, likely as a result of us using IEPR2003 data in our projections.

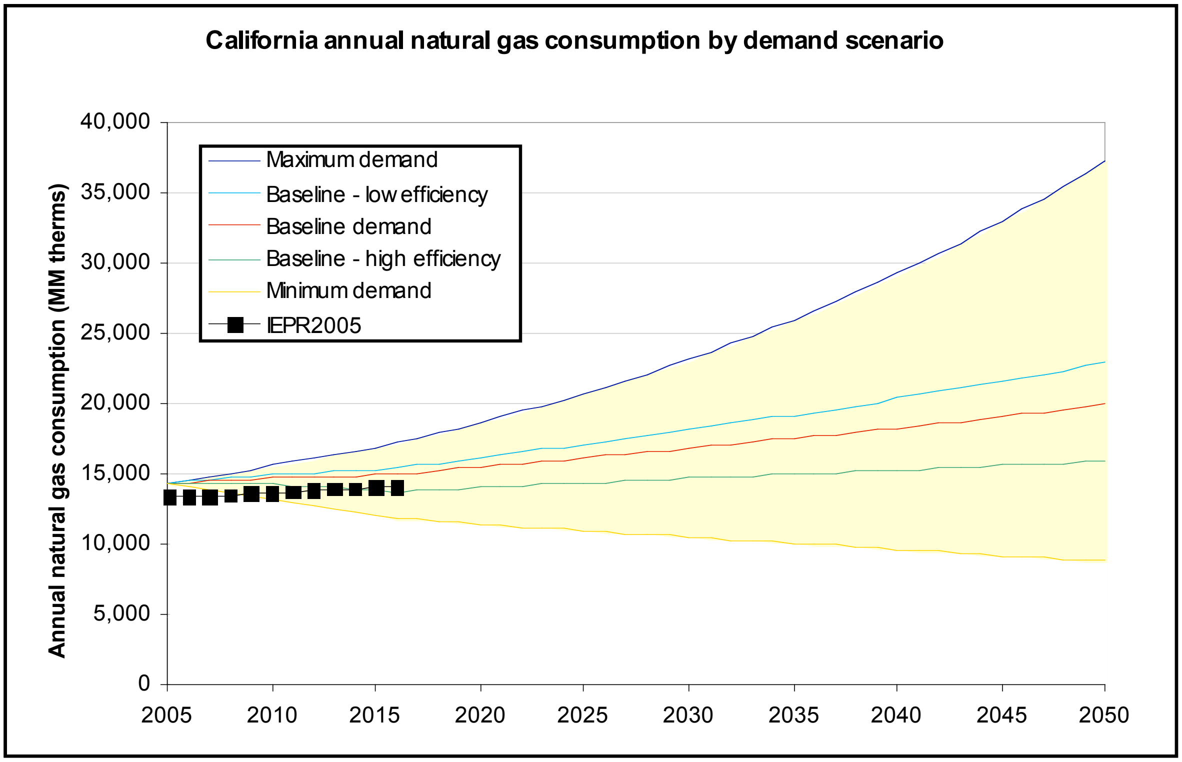


Figure 18 California natural gas consumption projections by demand scenario.

Similar to that for electricity demand, the range among the scenario projections is primarily accounted for by the demographic and economic forecasts. Comparing the moderate scenarios to the extreme ones, and recalling that both use identical efficiency assumptions, we see that efficiency accounts for about 17% of the variation between *Maximum demand* and *Baseline demand*, and about 36% of the variation between *Minimum demand* and *Baseline demand.*

The influence of the activity variables can be illustrated by comparing per-capita consumption (shown in Figure 19) to total consumption (Figure 18). While *Maximum demand* per-capita natural gas consumption is only 2.7 times greater than that of *Minimum demand,* final energy consumption is more than 4.2 times greater than the *Minimum demand* case.

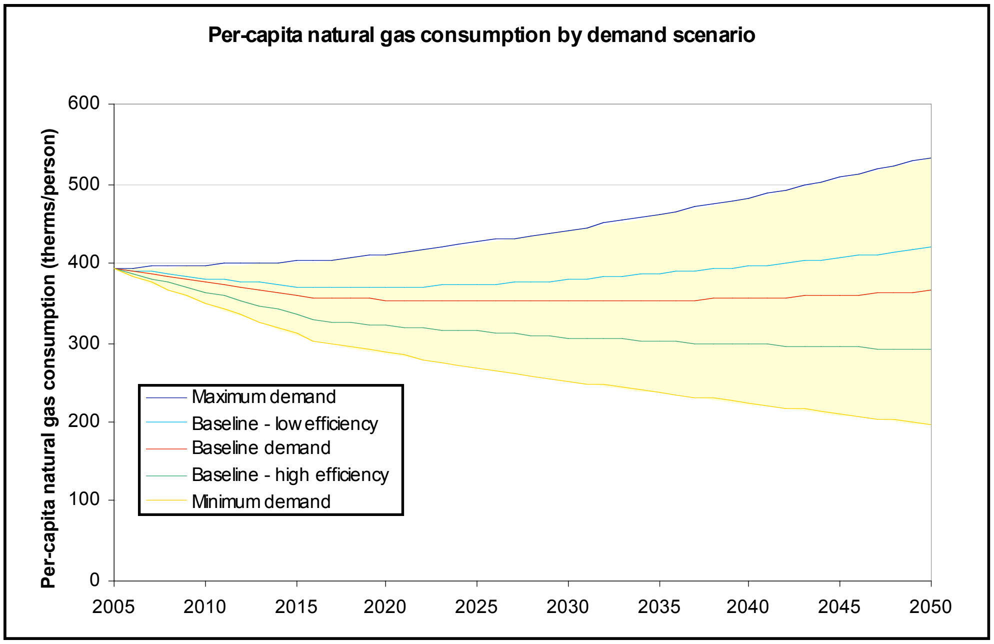


Figure 19 Per-capita natural gas consumption by demand scenario.

Figure 20 and Figure 21 illustrate the sectoral and regional consumption, respectively, for *Baseline demand*. The residential and industrial sectors account for the most natural gas usage (33% and 51% of total demand in 2050, respectively), which is primarily located in the PG&E and SCG planning areas. Also, looking at sectoral demands, we see that the kink in annual natural gas consumption visible in Figure 21 is a result of projected demand in the industrial sector. The methods leading to the discontinuity are described in *Section 6.4*, below.

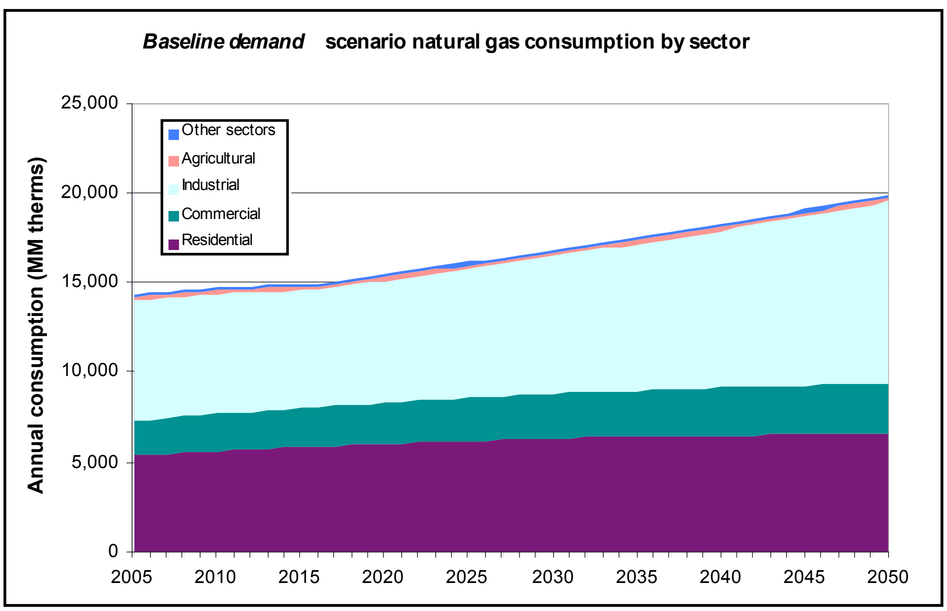


Figure 20 California natural gas consumption by sector for *Baseline demand*.

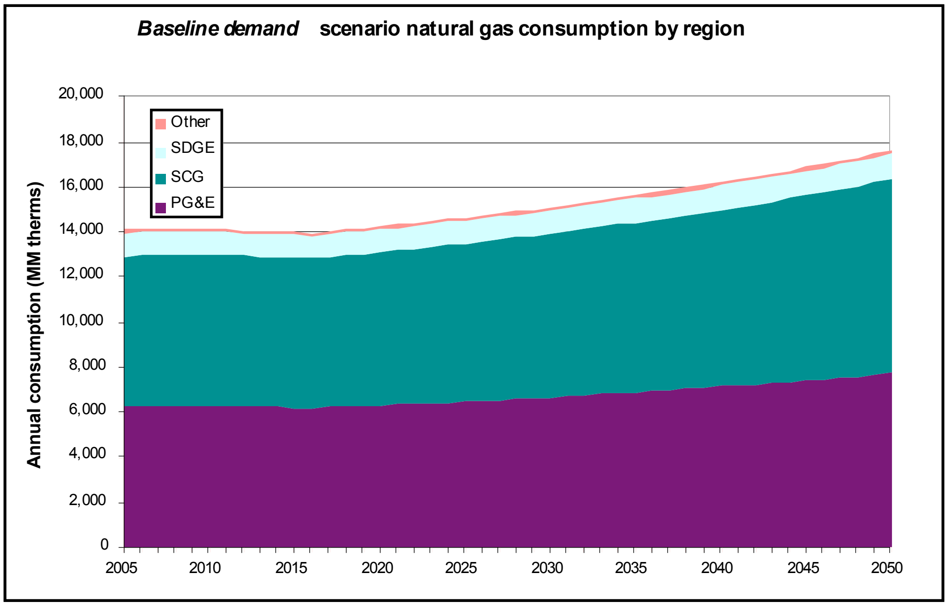


Figure 21 California natural gas consumption by region for *Baseline demand*.

6.2. Residential

6.2.1. Methods and assumptions

Annual natural gas consumption for the residential sector is defined similar to Equation 5, as the product of end use appliance saturation, UEC, and the number of households for each of six electric utility planning areas (the *Other* region is lumped into PG&E and SCE). We base our forecasts on data from IEPR2003, taking 2004 as the base year. Twelve appliance end uses, listed in Table 18, are modeled for each of the six regions. Appliance saturation rates and UECs in 2050 are projected according to scenario assumptions, and values in years 2005-2049 are derived from linear interpolation.

Table 18. Residential sector natural gas demand end uses.

End use
Central AC
Space heating
Hot water (dishwasher)
Hot water (clothes washer)
Basic water heating
Cooking
Clothes dryer
Solar water heating
Miscellaneous
Hot water (pool)
Solar pool pump
Hot water (hot tub)

We include three efficiency scenarios in our demand projections. The frozen efficiency case, used in *Maximum demand* and *Baseline - low efficiency*, sets year 2050 efficiency equal to the marginal efficiency of new technology in 2004. *Baseline demand* continues projected trends from IEPR2003 through 2050, based on average annual growth rates. Projected UECs in the baseline case are constrained by the high and low efficiency assumptions for each end use. Finally, in the high efficiency scenario, efficiency is projected to improve 40% by 2050, equal to technically feasible efficiency improvements in the sector (CEC, 2005c).

Minimum demand and *Baseline - high efficiency* fix appliance saturation rates at year 2004 levels, while the other scenarios continue saturation trends projected for 2003-2013 in IEPR2003.

The assumptions underlying the scenario projections for residential natural gas demand are described in Table 19. For simplicity, appliance UEC and saturation rates are aggregated into average household energy use. Average UEC values vary slightly between *Maximum demand* and *Baseline - low efficiency*, and between *Baseline - high efficiency* and *Minimum demand*, due to the geographical variability in energy consumption and the regional differences in household distribution among scenarios.

Table 19. Residential sector natural gas assumptions and projections.

	Maximum demand	Baseline - low efficiency	Baseline demand	Baseline - high efficiency	Minimum demand
Households (millions)					
Single-family					
2025	12.35 (48%)	10.67 (28%)	10.67 (28%)	10.67 (28%)	8.44 (1%)
2050	19.92 (138%)	12.93 (55%)	12.93 (55%)	12.93 (55%)	8.27 (-1%)
Multi-family					
2025	4.56 (20%)	4.61 (21%)	4.61 (21%)	4.61 (21%)	4.44 (16%)
2050	5.85 (54%)	5.26 (38%)	5.26 (38%)	5.26 (38%)	4.87 (28%)
Avg. household energy intensity (therms/household/year)					
Single-family					
2025	504.6 (-1%)	503.8 (-1%)	471.4 (-8%)	418.6 (-18%)	418.6 (-18%)
2050	497.9 (-2%)	495.7 (-3%)	425.3 (-17%)	307.8 (-40%)	307.8 (-40%)
Multi-family					
2025	302.1 (0%)	302.6 (0%)	290.0 (-4%)	251.2 (-17%)	251.2 (-17%)
2050	302.1 (0%)	303.5 (0%)	275.8 (-9%)	187.8 (-38%)	187.8 (-38%)
Residential natural gas demand (million therms)					
2025	7,497 (39%)	6,711 (25%)	6,218 (15%)	5,570 (3%)	4,629 (-14%)
2050	11,348 (111%)	7,872 (46%)	6,619 (23%)	4,876 (-10%)	3,439 (-36%)

* Values in parentheses show the percent increase compared to 2005.

6.2.2. Results

Figure 22 illustrates the scenario projections for California residential sector natural gas consumption. *Baseline demand* projects a 23% increase in consumption (relative to 2005) to 6,619 MM therms in 2050. *Maximum demand* sets residential natural gas use 71% higher than the *Baseline demand* scenario in 2050, and *Minimum demand* forecasts consumption that is 48% less than *Baseline demand*. In *Baseline - low efficiency*, year 2050 natural gas consumption is 19% higher than in *Baseline demand*, and in *Baseline - high efficiency,* natural gas consumption is 26% less than *Baseline demand*. The IEPR forecast is 4% less than *Baseline demand* in 2016.

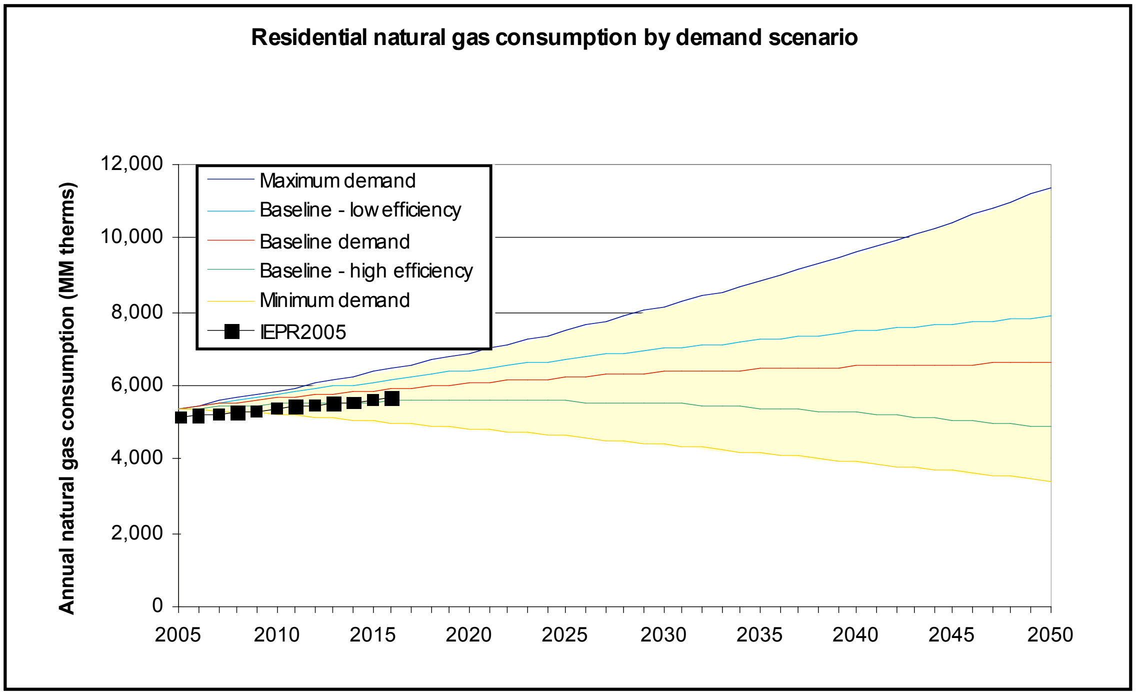


Figure 22 California residential sector natural gas consumption by demand scenario.

As discussed for residential electricity consumption, the flattening of the demand curves (except *Maximum demand*) reflects decreasing population growth rates projected in the latter decades of the analysis. This is not the case for *Maximum demand*, which sees relatively constant demand growth.

6.3. Commercial

6.3.1. Methods and assumptions

Annual natural gas consumption in the commercial sector is defined as the product of energy intensity (therms/ft^2) and floorspace for the four natural gas utility planning areas. We use EUI values by planning area, based on the IEPR2003 projections, as we lack energy consumption data by building type. The floorspace projections are aggregated from those forecast for the electricity utility planning areas, based on the relationships outlined in Table 3.

In *Maximum demand* and *Baseline - low efficiency*, EUI is frozen at projected 2005 levels. *Baseline demand* continues the projected regional trends from 2003-2013 through to 2050. And *Baseline - high efficiency* and *Minimum demand* use the same high efficiency assumptions as for commercial sector electricity consumption: EUI in existing buildings is assumed to decline by 15% in 2013, relative to year 2005 values, and all new floorspace is projected to use 40% less energy than in 2005.

Commercial sector natural gas demand projections, and the assumptions underlying them, are listed in Table 20. The values represent state-wide projections.

Table 20. Commercial sector natural gas assumptions and projections.

	Maximum demand	Baseline - low efficiency	Baseline demand	Baseline - high efficiency	Minimum demand
Floorspace (million ft^2)					
2025	8,408 (38%)	7,915 (30%)	7,915 (30%)	7,915 (30%)	7,063 (16%)
2050	12,969 (114%)	10,149 (67%)	10,149 (67%)	10,149 (67%)	8,295 (37%)
Avg. energy intensity (therms/ft^2/year)					
2025	0.322 (0%)	0.322 (0%)	0.302 (-6%)	0.286 (-11%)	0.286 (-11%)
2050	0.322 (0%)	0.322 (0%)	0.276 (-14%)	0.241 (-25%)	0.241 (-25%)
Commercial natural gas demand (million therms)					
2025	2,711 (38%)	2,552 (30%)	2,384 (22%)	2,261 (16%)	2,018 (3%)
2050	4,175 (113%)	3,267 (67%)	2,797 (43%)	2,451 (26%)	2,003 (3%)

* Values in parentheses show the percent increase compared to 2005.

6.3.2. Results

Figure 23 illustrates our commercial sector natural gas projections by scenario. Under the *Baseline demand* assumptions, demand is projected to increase 43% by 2050, to 2,797 MM therms. *Maximum demand* projects annual consumption in 2050 that is 49% greater than *Baseline demand*, and *Minimum demand* projects consumption that is 28% less. Natural gas consumption in 2050 is 17% greater and 12% less than *Baseline demand* in the moderate scenarios. *Baseline demand* is within 5% of the IEPR projections in 2016.

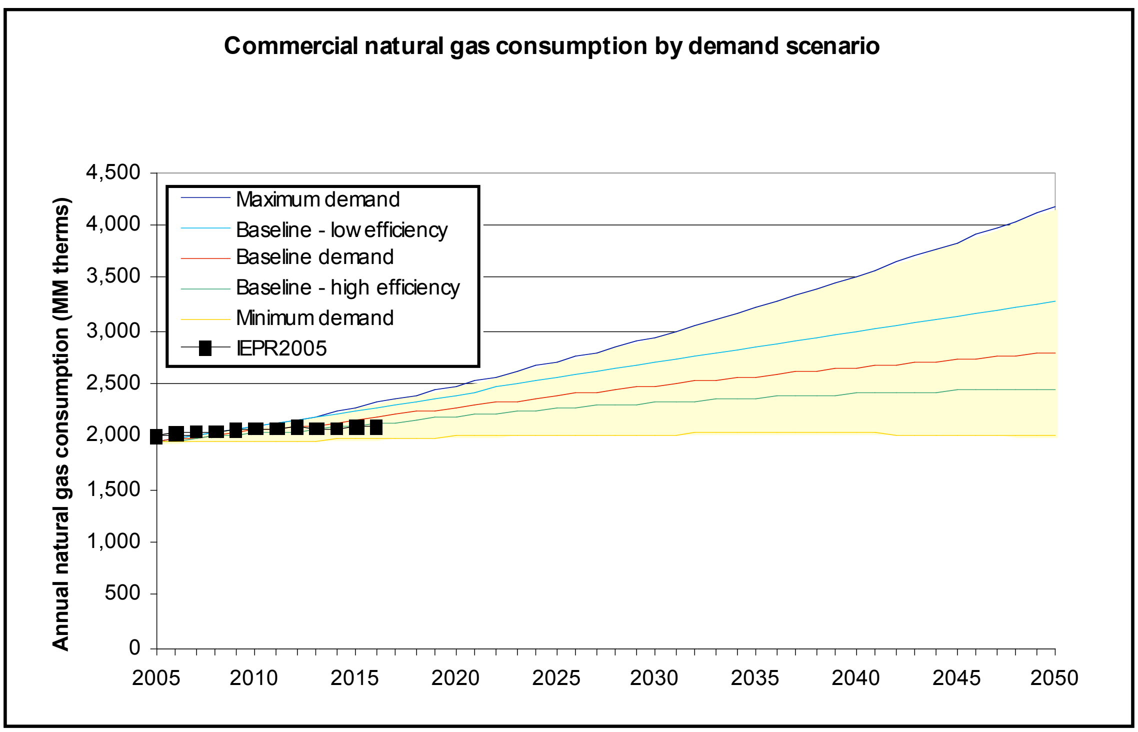


Figure 23 California commercial sector natural gas consumption by demand scenario.

6.4. Industrial

6.4.1. Methods and assumptions

Industrial sector natural gas consumption is defined as the product of shipments and EUI for the 33 industrial sub-sectors listed in Table 14 and four natural gas planning areas (see Equation 7). We define scenario energy efficiency using similar methods as described for industrial electricity. A scenario analysis of near-term energy efficiency potential in California was used to project near-term EUI (Itron et al, 2006), and beyond that, we applied the scenario growth rates from AEO2006 (EIA, 2006). The Itron report looks at energy efficiency potential in the manufacturing sector (SIC codes 20-39) for the three primary natural gas planning areas (PG&E, SCG, and SDGE). We attribute EUIs from PG&E to the *Other* planning area, and use the average EUI growth rates from the manufacturing sector to determine EUI in the mining sub-sectors (SIC codes 10-19).

Similar to the electricity projections, we apply efficiency gains from the report's "Naturally occurring" scenario to *Maximum demand* and *Baseline - low efficiency*, and assume EUI declines by 0.9% annually after 2016 in those scenarios. *Baseline demand* uses the "Base achievable" efficiency scenario, and the AEO reference case EUI growth rate after 2016 (-1.2%). *Minimum demand* and *Baseline - high efficiency* apply improvements from the "Technically achievable" scenario, and assume EUI improves by 1.4% annually after 2016.

The scenario natural gas projections for the industrial sector, and the assumptions we used in obtaining them, are described in Table 21. Only aggregate EUI for the entire sector is provided, for simplicity.

Table 21. Industrial sector natural gas assumptions and projections.

	Maximum demand	Baseline - low efficiency	Baseline demand	Baseline - high efficiency	Minimum demand
Shipments (million 2001$)					
2025	1,307 (122%)	967 (64%)	967 (64%)	967 (64%)	636 (8%)
2050	3,561 (505%)	1,914 (225%)	1,914 (225%)	1,914 (225%)	726 (23%)
Avg. energy intensity (therms/1000$)					
2025	7.8 (-31%)	7.8 (-31%)	7.5 (-34%)	6.4 (-43%)	6.4 (-43%)
2050	6.0 (-47%)	6.0 (-47%)	5.3 (-53%)	4.3 (-62%)	4.3 (-62%)
Industrial natural gas demand (million therms)					
2025	10,168 (52%)	7,523 (13%)	7,216 (8%)	6,199 (-7%)	4,078 (-39%)
2050	21,269 (219%)	11,434 (71%)	10,162 (52%)	8,247 (24%)	3,127 (-53%)

* Values in parentheses show the percent increase compared to 2005.

6.4.2. Results

Figure 24 illustrates the industrial sector natural gas demand scenarios. *Baseline demand* projects consumption to be 10,162 MM therms in 2050, 52% greater than in 2005. *Maximum demand* sees a very large increase in demand, 86% more so in 2050 than in the baseline, and *Minimum demand* is 69% less than *Baseline demand* in 2050. Year 2050 electricity demand in *Baseline – low efficiency* is 13% more than in *Baseline demand*, and *Baseline – high efficiency* sees demand that is 19% less than *Baseline demand*. *Baseline demand* is 9% greater than the IEPR2005 projections, largely due to differing data inputs.

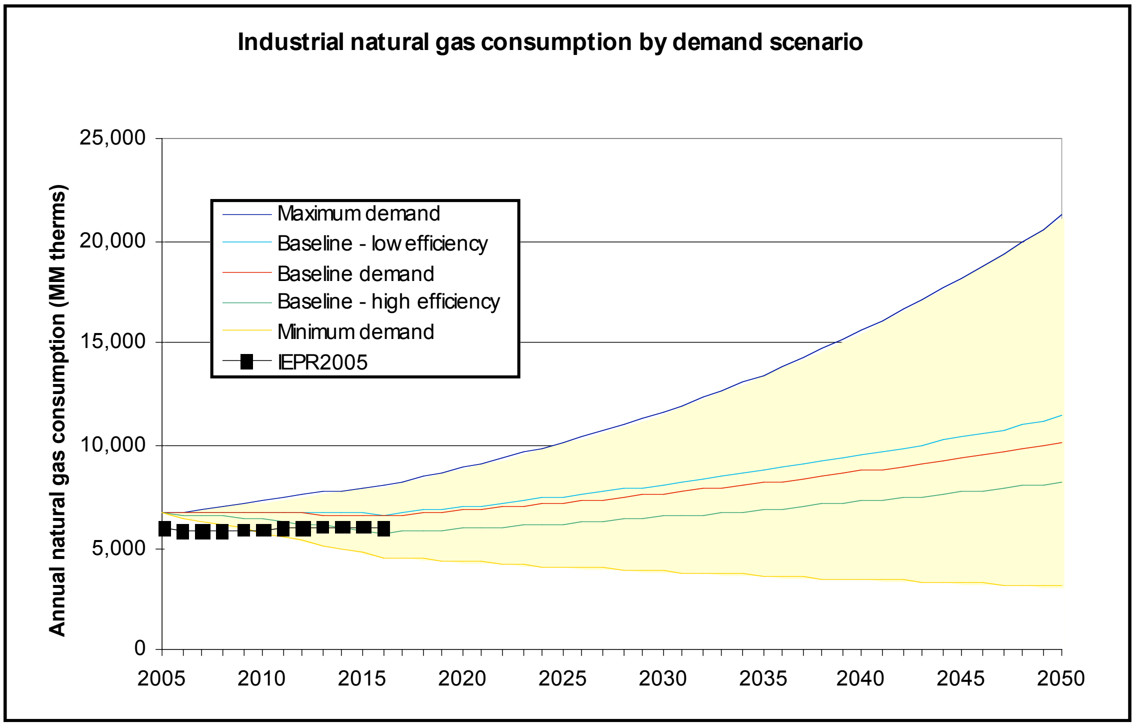


Figure 24 California industrial sector natural gas consumption by demand scenario.

The wide range in the shipment forecasts leads to the wide range visible for industrial sector natural gas consumption. Efficiency assumptions only account for 11% of the observed difference between the baseline and *Maximum demand*, and 27% of the difference between *Baseline demand* and *Minimum demand*.

The difference in the slope of the projections after 2016 is a result of the methods we used to project efficiency. In each scenario, the slope of the line becomes more positive after 2016, implying that the AEO growth rates are less in magnitude than the average growth rates from the Itron report. Initially, this finding might suggest that our *Maximum demand* efficiency assumptions are worse than a likely upper bound (i.e., worse than a likely worst case), and that our *Minimum demand* assumptions might not actually capture all efficiency improvements that are technically feasible. But those inferences are difficult to confirm without further analysis, as no level of efficiency improvement can continue unchecked.

6.5. Agricultural & *other* sectors

6.5.1. Methods and assumptions

Due to a lack of shipments or employment data for agriculture and the *other* sectors, energy consumption is projected through 2050 based on projected near-term trends in annual natural gas consumption. Projections are based upon data from IEPR2003, and disaggregated regionally only (i.e., there is no sub-sector classification).

We linearly extrapolate the 2003-2013 CEC projections through 2050 to develop *Baseline demand.* For the alternate scenarios, agricultural energy consumption is scaled by GSP, and *other* sector energy consumption is scaled by population. Thus, the difference in energy consumption for these two sectors is solely accounted for by demographic and economic factors (i.e., efficiency potential is not taken into account), and projections for the moderate scenarios equal those for *Baseline demand.*

6.5.2. Results

The natural gas demand projections for the agricultural and *other* sectors are illustrated in Figure 25 and Figure 26. In the agricultural sector, *Baseline demand* is projected to increase to 224 MM therms, or by 12% relative to 2005. *Maximum demand* sees an increase of 72% relative to current consumption, to 345 MM therms in 2050. And *Minimum demand* projects a decline of 47% by 2050, to 106 MM therms.

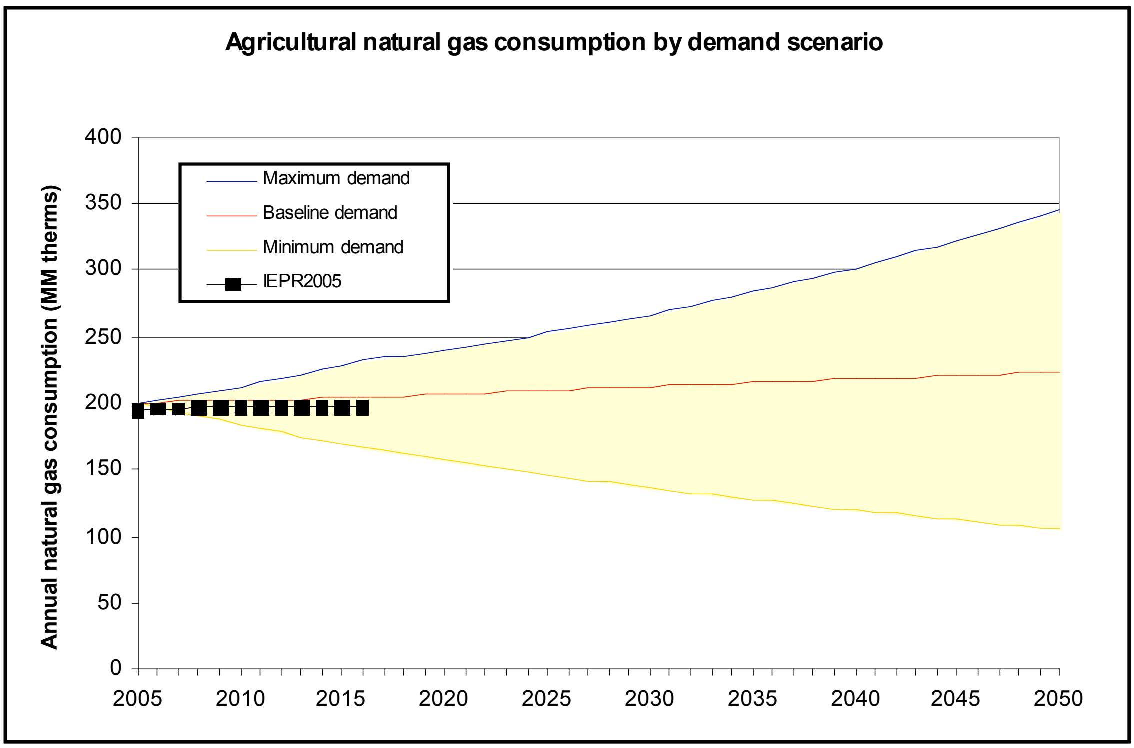


Figure 25 California agricultural sector natural gas consumption by demand scenario.

Baseline demand natural gas consumption in the *other* sectors is projected to increase 9% by 2050, to 175 MM therms. In *Maximum demand* and *Minimum demand*, year 2050 consumption is projected to increase to 224 MM therms and decrease to 143 MM therms compared to 2005, respectively. These correspond to a 39% increase over 2005 consumption, and an 11% decrease.

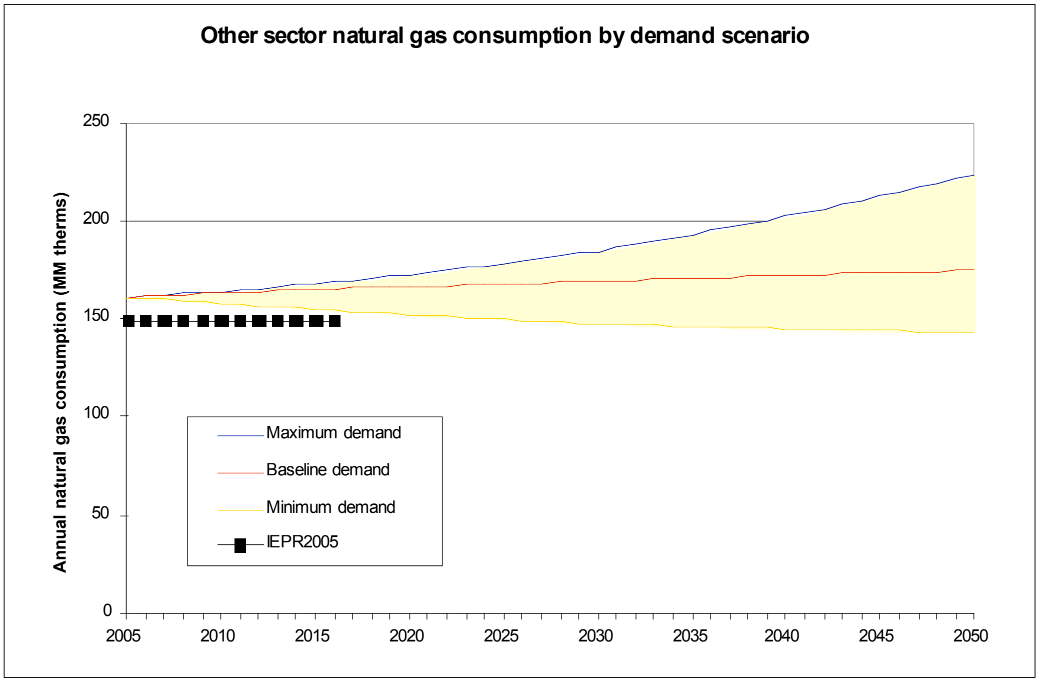


Figure 26 California *other* sector natural gas consumption by demand scenario.

6.6. Peak and seasonal demand projections

6.6.1. Methods and assumptions

Seasonal demands are projected based on California sector-specific monthly natural gas consumption data from the EIA. We average the month-by-month percentage of a given year's natural gas consumption, and take the monthly average over several years to develop a monthly load curve. Projected monthly natural gas demands are determined by multiplying sector consumption in a given year by the monthly load curve. For the residential and commercial sectors, we average 17 years worth of data (1989-2005), and for the industrial sector, 5 years (2001-2005). We distribute agricultural and *other* sector demands evenly throughout the year, due to the lack of data for seasonal demand variation for those sectors.

Monthly load curves for the three primary demand sectors are illustrated in Figure 27. Natural gas demand exhibits a strong winter peak in residential usage due to heating requirements. *Other* sectors do not exhibit this strong seasonal dependence in natural gas usage, and consequently, January is the peak demand month for aggregate natural gas demand across all sectors (excepting electricity generation).

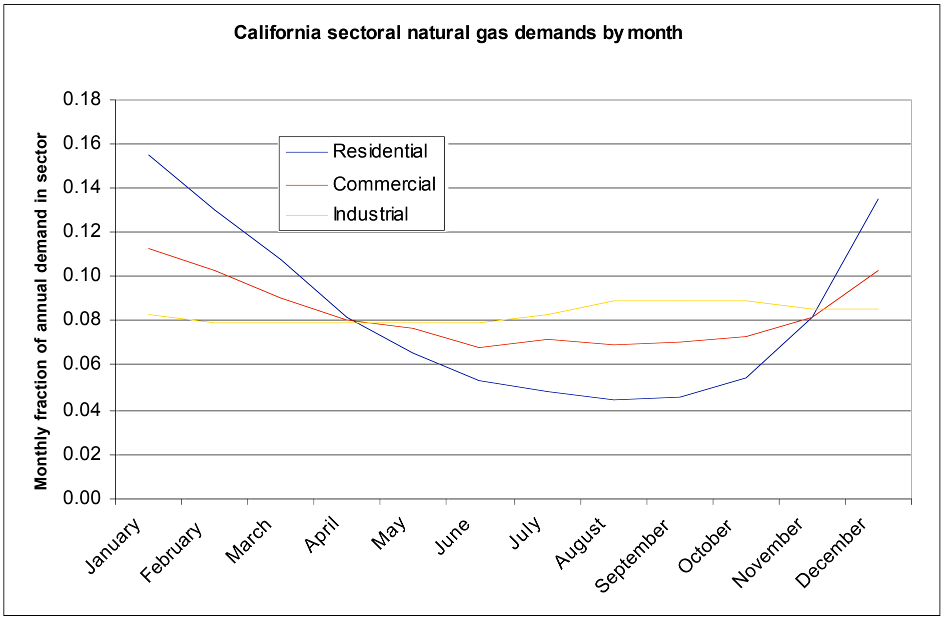


Figure 27 California monthly natural gas demand by sector.

6.6.2. Results

Figure 28 shows January (i.e., peak-month) natural gas demand by demand scenario. In *Baseline demand*, peak demand grows to 2,211 MM therms/month in 2050, or by 35% compared to 2005. *Maximum demand* projects a 127% increase compared to 2005, while *Minimum demand* sees a 32% decline. *Baseline – low efficiency* and *Baseline – high efficiency* see a 35% increase, and an 8% increase, respectively.

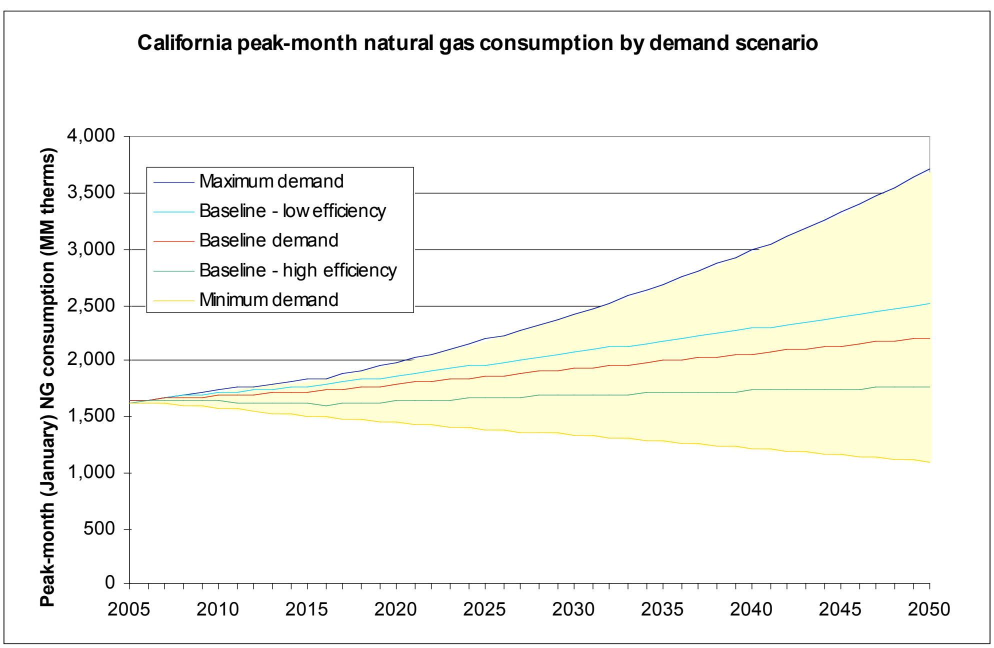


Figure 28 California peak-month natural gas projections by demand scenario.

These numbers are not directly proportional to the annual consumption projections due to variability among scenarios in the fraction of annual demand by sector. For example, in *Maximum demand*, where fast growing shipment projections lead to a disproportionate fraction of annual consumption coming from the industrial sector (relative to the other scenarios), peak-month demand grows slower than total consumption. This is a result of the relatively flat seasonal demand curve for the industrial sector, and leads annual consumption to grow 16% faster than peak demand, on average. The opposite is true for *Minimum demand*, which sees the highest fraction of residential and commercial demands, leading consumption to fall faster than peak demand.

7. TRANSPORTATION FUEL

Transportation fuel, predominately derived from petroleum, accounts for about half of total energy use in California. Given the constraints on in-state refinery capacity, quantifying transportation fuel demand is critical for determining additional capacity for the supply sector. And strategies for reducing growth in gasoline and diesel demand are important for reducing price spikes and other disruptions. *Baseline demand* incorporates trends for travel demand, vehicle efficiency and transportation fuel trends from the 2005 IEPR transportation section, assuming no significant new policies or alternative fuels penetration. The alternative scenarios are useful constructs because they attempt to layout a range of possible trajectories of total demand for travel (VMT), vehicle types and vehicle fuel economy for specific sets of assumptions. Some of the assumptions that underlie the alternative scenarios are an attempt to find reasonable bounds for key drivers that determine travel and fuel demands. The *Maximum demand* and *Minimum demand* scenarios link many of these extreme assumptions together to provide an estimate of what very high and low demands might look like.

The *Baseline demand* scenario is based upon initial data from runs of CEC's CalCARS model to 2025 using the medium fuel price scenario with no greenhouse gas regulations in place. The fuel demand projections for light-duty vehicles for the baseline and alternative scenarios are generated by a vehicle stock turnover model (VSTM) with key inputs – such as distribution of sales by vehicle class, fuel economy and average VMT – as the major assumptions that change in the scenarios. The VSTM tracks vehicle sales and fleet characteristics for 15 different vehicle types (from subcompacts to large SUVs). Additionally, each scenario also determines heavy-duty and air travel fuel demands based upon population, economic, and efficiency assumptions.

7.1. Annual Light-Duty Fuel Demand Forecasts

7.1.1. Methods and assumptions

Our alternative demand scenarios for transportation fuels project the demands of only three fuels through 2050 – gasoline, diesel and aircraft fuel. Ethanol is projected within these scenarios as an additive component of gasoline fuel (as an oxygenate at 5.7% by volume) rather than as a primary component of the fuel. In future work, modeling of the advanced transportation energy supply pathways and vehicles will include other transportation fuels (e.g., hydrogen and electricity), but these are not included in our initial alternative demand scenarios.

The goal of the "background" alternative scenarios presented in this report is to provide the context in which the introduction of alternative fuel vehicles might take place. They also serve to provide a means of assessing the emissions and energy impacts of introducing alternative fuels, by providing a "background" or baseline level of fuel demand and emissions from the use of conventional fuels and vehicles to meet travel demands.

The scenarios are built upon projections for new vehicle sales, vehicle miles traveled and fuel economy of each of 15 different vehicle classes (see Appendix for detailed list) which can be powered by 3 different powertrains (conventional gasoline, gasoline hybrid, and diesel). The fuel demands in the alternative scenarios are calculated based upon the set of specific assumptions about population, vehicle fuel economy, VMT demands, and new car sales.

Table 22 shows some of the key input assumptions for modeling the alternative scenarios. These assumptions were informed by our knowledge and opinion about feasible efficiency and vehicle scenarios.

Table 22. Key assumptions and drivers for light-duty fuel demand in alternate scenarios.

	Minimum Demand	Baseline - Low Demand	Baseline Demand	Baseline - High Demand	Maximum Demand
Demographic variables					
Population (millions)					
2025	41.0 (12%)	45.9 (26%)	46.0 (26%)	45.9 (26%)	48.8 (33%)
2050	44.8 (22%)	54.8 (50%)	54.8 (50%)	54.8 (50%)	70.0 (92%)
Total vehicles (millions)					
2025	27.0 (7%)	38.3 (49%)	38.4 (48%)	38.3 (49%)	38.8 (54%)
2050	29.8 (18%)	51.4 (100%)	51.4 (98%)	51.4 (100%)	81.9 (226%)
Vehicle miles traveled per-capita (miles)					
2025	6,937 (-14%)	8,385 (-1%)	9,795 (20%)	10,496 (23%)	10,487 (23%)
2050	5,583 (-31%)	8,434 (0%)	10,833 (33%)	12,916 (51%)	12,376 (45%)
Light duty vehicle market fraction of car/trucks					
2025	56%/44%	52%/48%	48%/52%	44%/56%	44%/56%
2050	69%/31%	59%/41%	47%/53%	39%/61%	39%/61%
Fleet-average fuel economy (mpg)					
2025	29 (41%)	23 (16%)	22 (10%)	21 (5%)	21 (4%)
2050	49 (141%)	32 (61%)	26 (26%)	24 (18%)	23 (15%)

* Value in parentheses shows the percent increase from the 2005 value.

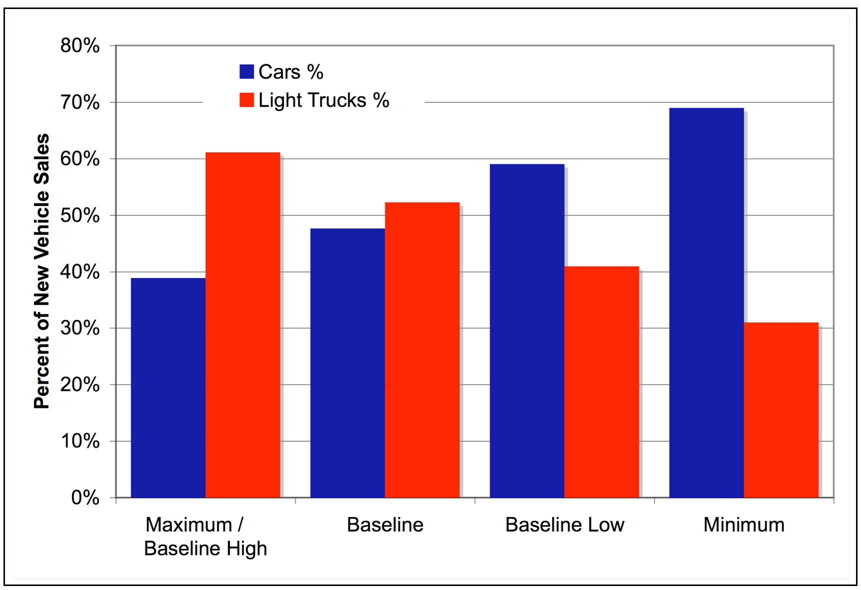


Figure 29 Distribution of new car and truck sales in 2050 in the alternative scenarios.

Each scenario (*Baseline demand, Minimum demand, Baseline – low demand, Baseline – high demand* and *Maximum demand*) is constructed using a set of input assumptions that determines the activity level (i.e., population and vehicle miles traveled per capita) and the energy efficiency of vehicles (i.e., the mix of vehicles and their fuel economy). The *Maximum demand* and *Minimum demand* scenarios are meant to provide the high and low bounds on energy use in California while the *Baseline – low demand* and *Baseline – high demand* scenarios explore the impact of changing VMT, fuel economy and vehicle mix on the *Baseline demand* scenario. As with the electricity and natural gas scenarios, *Baseline – low demand* and *Baseline – high demand* share the same population and economic assumptions and drivers as the baseline scenario, while the *Maximum demand* and *Minimum demand* scenarios reflect high and low values for population and GSP growth in the state. However, unlike the electricity and natural gas scenarios, the efficiency assumptions for the *Baseline – low demand* and *Baseline – high demand* cases are not limited to being equal to the *Minimum demand* and *Maximum demand* scenarios, respectively. The exact assumptions for these scenarios are laid out below.

The fleet fuel economy for each of the scenarios is determined by several factors, all as a function of model year: the distribution of vehicles and vehicle sales by class within the fleet, the fuel economy of the different vehicle classes, and total new vehicle sales. Figure 29 shows the breakdown of new vehicle sales into cars and trucks for 2050 in each of the alternative scenarios, which represents the distribution of vehicles into different vehicle classes. The *Minimum demand* scenario shows a shift back to a high percentage of car sales, while the *Maximum demand* scenario shows a continued shift towards truck sales. The CalCars model describes the fuel economy of each vehicle type in the 2003 base year and Figure 30 shows the assumed relative fuel economy for cars and trucks in each of the alternate scenarios. The average percentage fuel economy improvement for new vehicles sold in the *Minimum demand* scenario is based upon the Pavley regulations (AB1493) to 2016, where GHG emission reduction to meet the regulations is driven solely by fuel economy improvements rather than changes in fuel carbon content. After 2016, half the rate of improvement required by Pavley is assumed out to 2050, resulting in a 140% improvement in fuel economy for new cars (to 65 mpg) and 80% improvement in light trucks (to 41 mpg) by 2050. The more moderate fuel economy changes for the *Baseline – low demand* scenario are based on meeting the equivalent Pavley fuel economy (43 mpg for cars and 30 mpg for light trucks) by 2050 (instead of 2016). Given the very low fuel economy increase projected by *Baseline demand*, the *Baseline – high demand* and *Maximum demand* cases also assume the same relative fuel economy improvements for each vehicle class (15% improvement for cars and 24% improvement for light trucks).

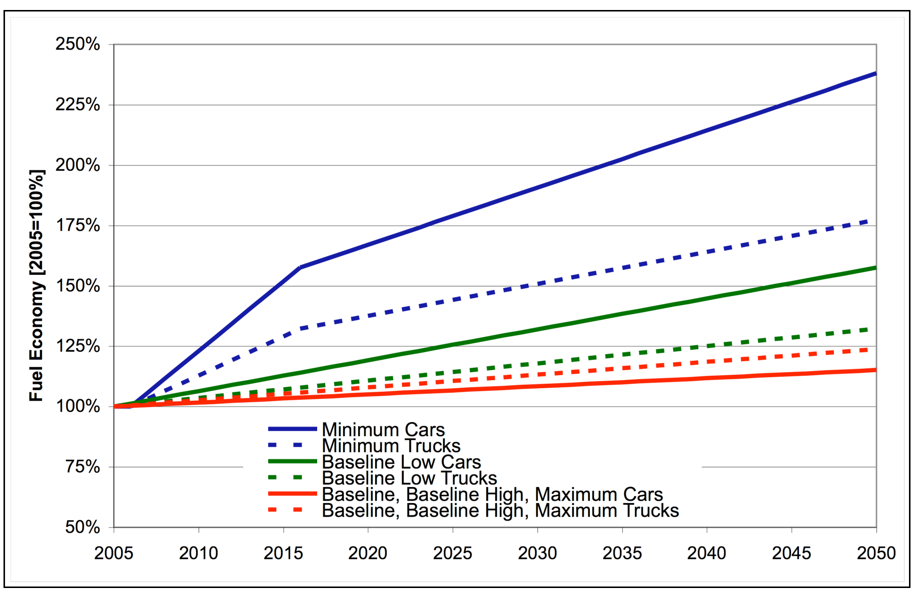


Figure 30 Relative fuel economy improvements for new sales by vehicle class and scenario.

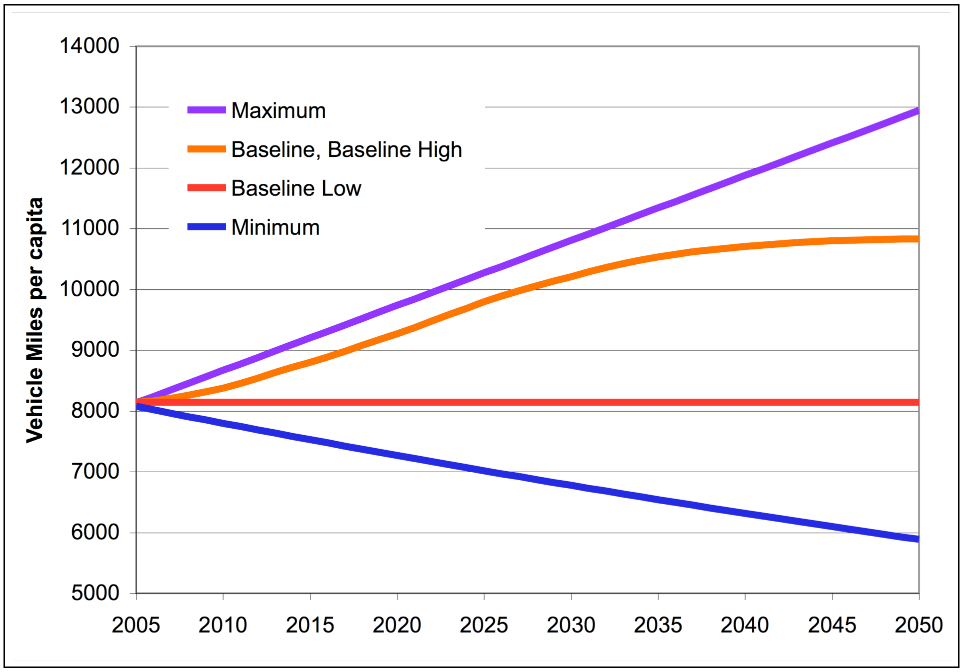


Figure 31 Input assumptions about average vehicle miles traveled per capita for the alternative scenarios.

Figure 31 shows the input assumptions for each of the alternative scenarios for vehicle miles traveled per capita for each of the model years. The increased VMT/capita in *Maximum demand* can be attributed to longer commute distances and greater individual travel demand. The *Baseline demand* scenario also assumes significant increases in VMT/capita, though it levels out at the end of the modeling period. *Baseline – low demand* assumes constant VMT/capita while *Minimum demand* assumes that individual VMT decreases linearly so that the value in 2050 (just under 6000 miles/person/year) is equal to the US average from 2000.

Baseline Fuel Demand Scenario

Baseline demand is based upon the CEC's forecasts and modeling to 2025. Many of the important drivers for the scenario (population, VMT/capita, vehicle fuel economy, etc.) are shown in Table 22. This case assumes very slow efficiency increases and a growing population and travel demand. VMT/capita is expected to increase 33% while average fleet fuel economy increases only 26% to 26 mpg by 2050. Given the large increase in population (50%), total fuel demand also increases by 64% from 2005-2050 in *Baseline demand*. The scenario is a continuation of current trends, and as a result, shows low levels of adoption of more efficient vehicles (hybrids and diesels) and no shift in the distribution of vehicle classes.

Minimum Fuel Demand Scenario

In contrast to the *Baseline demand* scenario, *Minimum demand* seeks to capture a future energy demand trajectory that is marked by low population growth, high-efficiency vehicles and reduced VMT in light-duty vehicles. As seen in Table 22*,* the population increases to about 45 million people, while VMT/capita declines by 31% to the year 2000 US average in 2050. This reduction in travel demand, coupled with a dramatic increase in vehicle fuel economy (fleet average increases by 41%), leads to a significant reduction in total fuel demand. Also shown on the table is the ratio of cars to light trucks, and this scenario reflects a shift back towards more efficient vehicle classes such as cars (69% of new vehicle sales in 2050) and away from trucks (31% of sales in 2050). The assumptions about these key drivers help to reduce light-duty fuel demand by 64% between 2005 and 2050.

Maximum Fuel Demand Scenario

Like the *Minimum demand* scenario, *Maximum demand* represents another extreme with respect to total transportation fuel demand for the State. The main drivers that lead to high total fuel demand include a high population growth projection, increasing VMT/capita, small increases in vehicle fuel efficiency, and a continued shift towards trucks and low fuel efficiency vehicle classes. The fuel economy assumption for each vehicle class is equivalent to the *Baseline demand* scenario, which assumes only small incremental improvements in fuel economy (15% for cars and 24% for trucks from 2005-2050). Population increases in this scenario to 70 million by 2050, nearly double the population in 2005. VMT per-capita also increases significantly (by 45% in 2050, a gain of 1% annually) in this scenario, and the market continues to shift to low fuel efficiency vehicles, as trucks make up 61% of new light-duty vehicle sales in 2050. Average fleet fuel economy stagnates, and by 2050 is only 15% higher (3 mpg) than in 2005. By 2050, total state-wide fuel consumption reaches 42 billion gallons (gasoline equivalent), an increase of 132% over the year 2005 fuel demand.

Baseline - Low Fuel Demand Scenario

The *Baseline – low demand* scenario uses population and sales/capita assumptions from the *Baseline demand* scenario. However, the fuel economy is assumed to increase moderately over the next 45 years, achieving equivalent Pavley fuel economy for new vehicles (58% increase to 43.3 mpg for cars and 32% increase to 30.7 for trucks) by 2050 (instead of 2016). The scenario also assumes a moderate shift towards more efficient hybrid and diesel drivetrains, and a moderate shift towards smaller vehicle classes and cars (59% car sales by 2050). VMT per-capita is constant throughout the modeling period. These assumptions lead to a small (12%) increase in the total fuel demanded over the 45-year timeframe.

Baseline - High Fuel Demand Scenario

The *Baseline - high demand* fuel demand scenario uses population, vehicle and class sales and fuel economy assumptions from the *Baseline demand* scenario. However, this scenario assumes that VMT/capita increases faster than in *Baseline demand*, and is based upon VMT values from the *Maximum demand* scenario. The increase in travel demand from the *Baseline* scenario is the major driver leading to the fuel demand differences between the two scenarios – almost a doubling compared to *Baseline demand*.

7.1.2. Results

Figure 32 shows the total fuel demand for each of the five scenarios. One of the important aspects of the alternate "background" scenarios and their use in the energy system modeling is that the aggregate energy demand, in this case, petroleum-based transportation fuels, shows a wide range of possible trajectories in the future. California's light-duty road transport fuel demand in 2050 ranges from about 5.3 billion gallons (gasoline equivalent) to over 29 billion gallons. These extreme scenarios (both *Maximum demand* and *Minimum demand*) have profound implications for the state and the required energy infrastructure. And it is in these very different contexts that advanced vehicles with alternative fuels may be introduced.

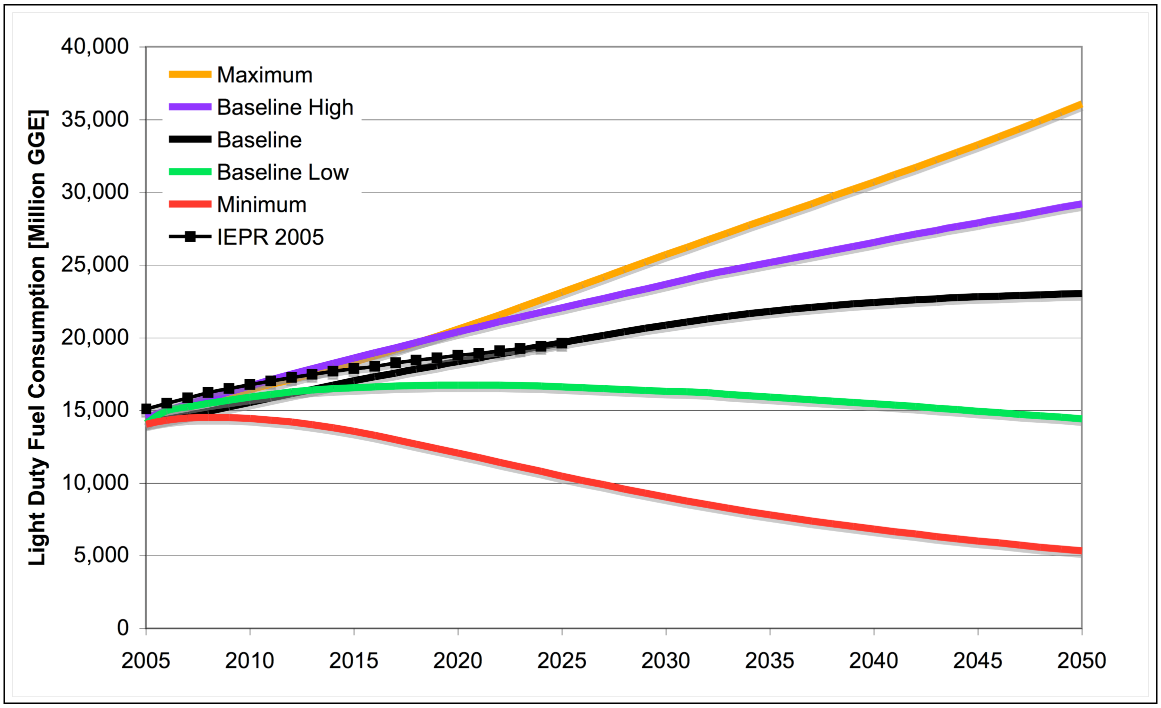


Figure 32 Light-duty fuel demands (gallons of gasoline equivalent) for each of the five alternate scenarios.

7.2. Heavy Duty and Aircraft Fuel Demands

Figure 33 and Figure 34 show the annual fuel demands for heavy-duty vehicles and aircraft, respectively. *Baseline demand* is based upon CEC projections for fuel usage out to 2025. To determine the heavy-duty and aircraft fuel demands for the alternate scenarios, we used ratios of efficiency and GSP between the alternative scenarios and *Baseline demand* to scale fuel demand (see Table 23). The efficiencies of freight and aircraft fleets were taken from the EIA's high technology (for *Minimum demand*) and 2005 technology (for *Maximum demand*). Heavy-duty fuel demand is determined by heavy-duty activity (which is scaled to the ratio of state GSP in the alternative and baseline scenarios) and the change in heavy-duty fuel economy.

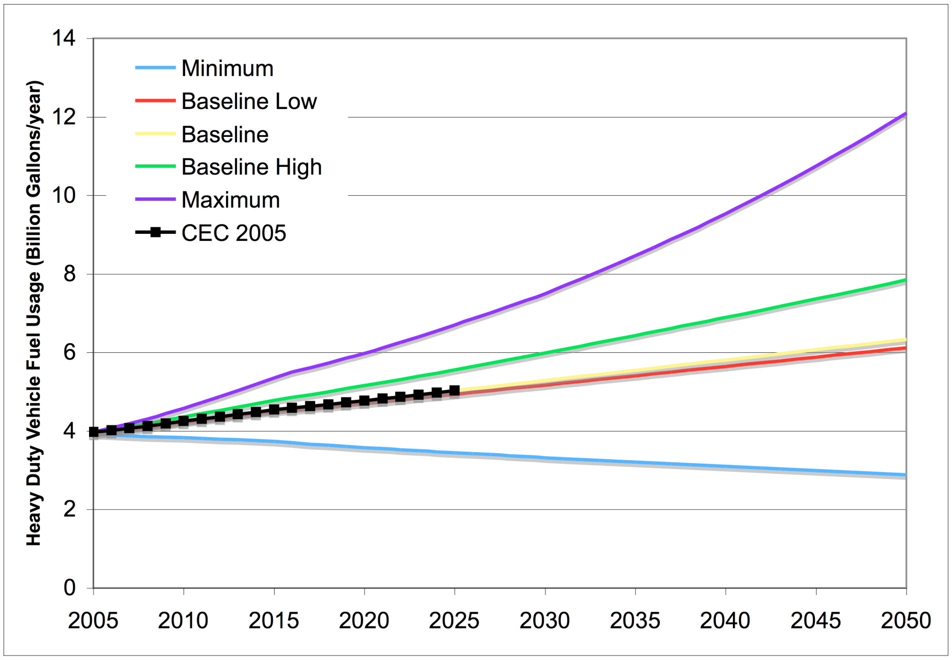


Figure 33 Heavy-duty vehicle fuel demand for each alternate scenario.

Aircraft fuel demand is driven in the scenarios by airline seat-mile, (scaled to both population and GSP/capita) and changes in airline fuel economy. The *Baseline demand* scenario aircraft fuel demand is designed to match the 2005 IPER Transportation fuel demand to 2025. The rate of increase in per-capita seat-miles is slightly lower for the remainder of the *Baseline demand* fuel consumption (2% annually for 2023-2050) than for the initial period (2.4 % annually for 2005-2025). Heavy-duty vehicles and aircraft fuel economy for *Minimum demand* and *Maximum demand* were based on EIA's 2006 Annual Energy Outlook (EIA 2006). Total aircraft fuel demand increases quickly due to large increases in air travel demand, as seen in Table 23. As a result, aircraft fuel becomes a larger percentage of total fuel demand in 2050.

Table 23. Heavy-duty and aircraft activity and efficiency assumptions

	Minimum demand	Baseline - High demand	Baseline demand	Baseline - Low demand	Maximum demand
Heavy-duty activity (relative to *Baseline demand*)					
2025	0.78 (-21.7%)	1.00 (0.0%)	1.00 (0.0%)	1.00 (0.0%)	1.13 (13.5%)
2050	0.58 (-42.4%)	1.00 (0.0%)	1.00 (0.0%)	1.00 (0.0%)	1.21 (20.6%)
Heavy Duty FE (mpg)					
2025	6.8 (11.2%)	6.8 (11.2%)	6.7 (10.6%)	6.0 (0.0%)	6.0 (0.0%)
2050	7.7 (26.6%)	7.7 (26.6%)	7.5 (23.9%)	6.0 (0.0%)	6.0 (0.0%)
Aircraft demand (billion seat-miles)					
2025	385 (90.7%)	552 (172.9%)	552 (172.9%)	552 (172.9%)	665 (228.9%)
2050	332 (64.5%)	706 (249.1%)	706 (249.1%)	706 (249.1%)	1087 (437.9%)
Aircraft fuel economy multiplier (relative to *Baseline demand*)					
2025	1.25 (22.0%)	1.25 (22.0%)	1.00 (0.0%)	0.83 (-15.6%)	0.83 (-15.6%)
2050	1.28 (24.8%)	1.28 (24.8%)	1.00 (0.0%)	0.67 (-31.8%)	0.67 (-31.8%)

* Values in parentheses show percent compared to 2005.

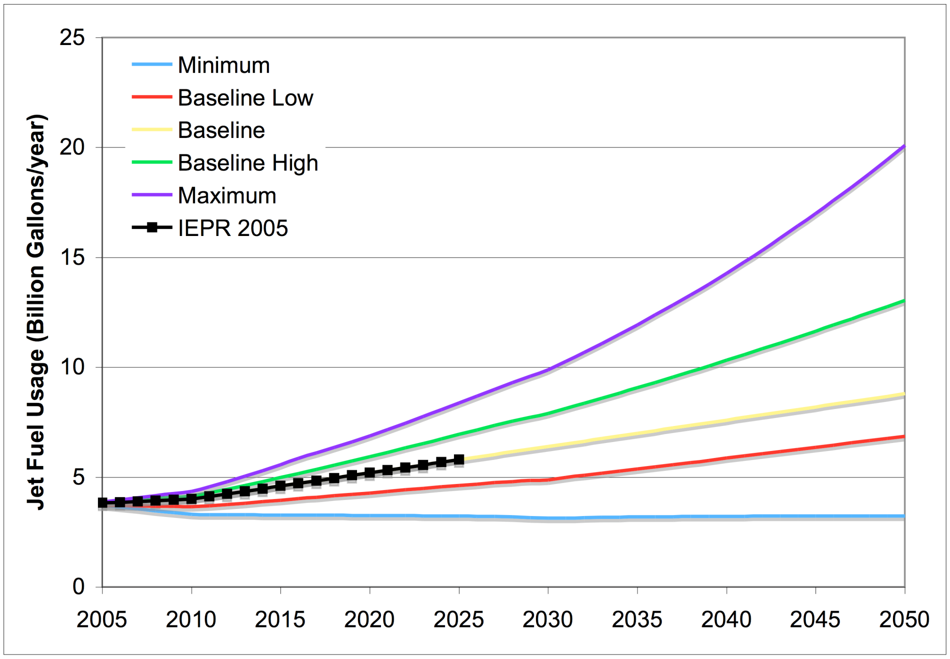


Figure 34 Jet fuel demand for each alternate scenario.

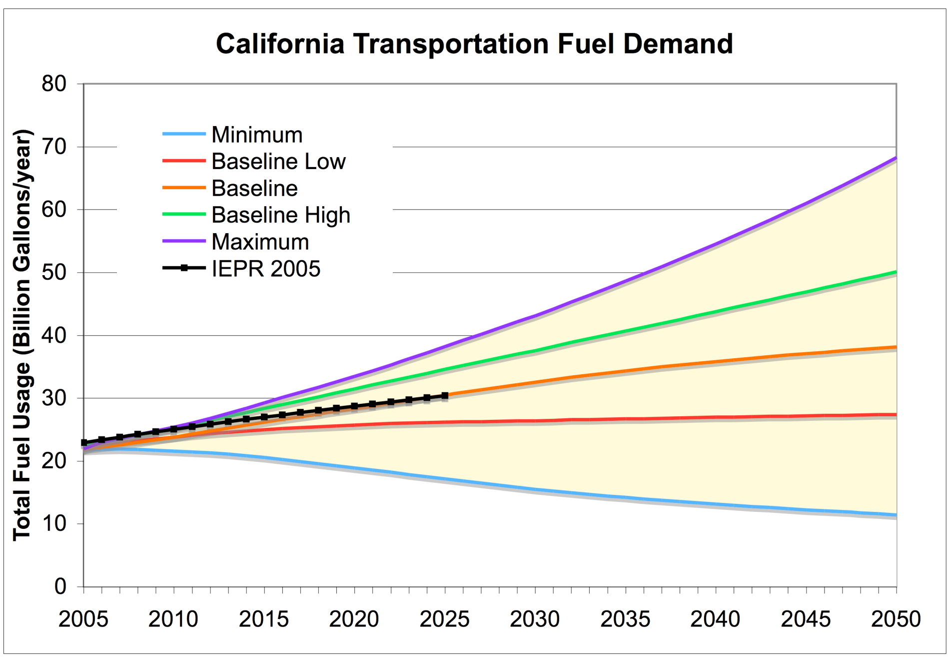


Figure 35 Total fuel demand (light-duty, heavy-duty and aircraft) for alternative scenarios.

Heavy-duty and aircraft fuel demands are added to light-duty fuel demands shown in Figure 32 to generate total fuel demands for the State (shown in Figure 35). Given the wide range of population, economic and efficiency assumptions between *Minimum demand* and *Maximum demand*, the total fuel demand in 2050 varies between 12 and 68 billion gallons (about a factor of 6 difference). The implications of this wide demand range is significant, as the necessary infrastructure, resource requirements and impacts on complementary energy systems will be quite different for the different scenarios. The structure, constraints, operation and layout of these systems will be vastly different and should provide a useful context in which to understand the impacts associated with the introduction of advanced transportation fuel and vehicle options.

7.3. Temporal Disaggregation

The previous section outlined the projections for annual fuel demand, but the distribution of demand is not constant on a monthly, daily or hourly basis. Annual fuel usage peaks in the summer months, and the *Baseline demand* scenario disaggregates the annual fuel demand for gasoline, ethanol and diesel by month and again by hour of the week (see Figure 36). Each day of the week has a slightly different total fuel demand and hourly fueling profile (Nexant 2005). The hourly profile has important implications for the cost and design of refueling stations, especially those that dispense fuel as a compressed gas such as CNG or H_2 (though these do not have any projected demand in these 'background' scenarios).

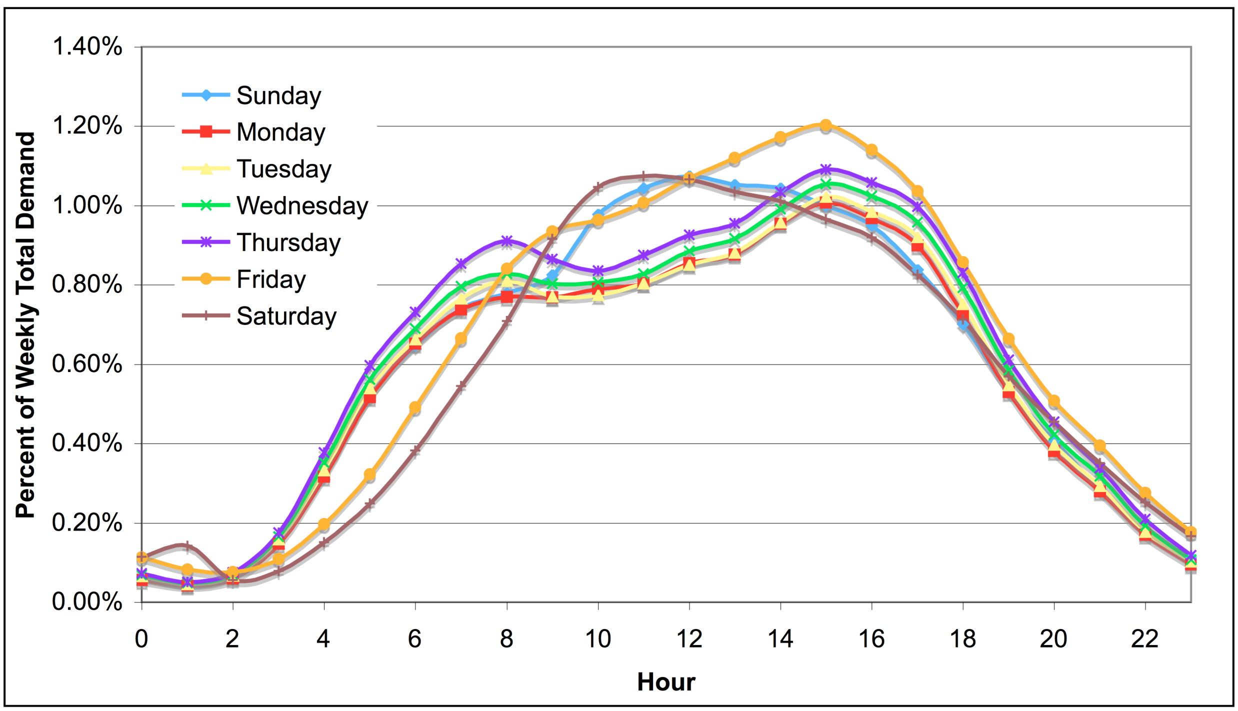


Figure 36 Representative hourly and daily fuel demand at refueling stations.

7.4. Transportation Fuel Summary

Transportation fuel shows the widest variation between *Minimum demand* and *Maximum demand* of any of the energy sectors. Given historical trends in vehicle fuel economy, the *Baseline demand* scenario does not assume much efficiency improvement for light-duty vehicles. In fact, the same baseline fuel economy is used in the *Maximum demand* scenario as well, though it is also coupled with an increase in VMT and a further shift towards light trucks. This is contrasted with *Minimum demand,* which assumes extensive improvements in vehicle fuel economy that are combined with travel demand reductions to yield fuel demand reductions over time.

Light duty vehicle fuel demand is one component of total fuel demand. Airline travel and associated fuel demand is expected to increase its share of total fuel demand in all scenarios. These scenarios are important because they identify the potential composition of the fleet of light duty vehicles and the contribution of various factors such as fuel economy, VMT, and population to total fuel demand. These 'background' transportation scenarios are useful for energy supply modeling because they provide an important context to understand how the introduction of advanced technology vehicles running on alternative (non-petroleum) fuels will substitute for, and affect, overall fuel demand.

8. SUMMARY

This report and accompanying spreadsheets provide the annual demand for electricity, natural gas and transportation fuel from 2005 to 2050 for scenarios that span a wide range of demographic, economic and technology development assumptions. The report covers the methods and assumptions for generating energy demands for each energy type and sector. The level of future energy demand has important implications on future energy supplies for California, with respect to availability of resources, cost and reliability of energy services, and environmental implications for meeting energy demand. The range of scenarios developed here and their associated energy demands is quite large, which provides a useful set of inputs into future energy system modeling to assess these issues.

8.1. Electricity Demands

The total electricity demand for each of the scenarios is presented in Figure 37. Also shown on the figure is the CEC's electricity projection from the 2005 Integrated Energy Policy Report (IEPR2005). The range of annual electricity demand varies widely among the five different scenarios, from 217,000 GWh to 688,000 GWh in 2050. This factor of three difference illustrates the multiplicative impacts of population growth, per-capita activity growth and technology and efficiency assumptions on total energy demand. *Minimum demand* shows a 20% reduction in electricity demand despite growth (albeit slow) in population and the state economy. *Maximum demand* shows a doubling of electricity demand because of population growth, growth in economic and activity drivers (such as industrial shipments and commercial floorspace), and minor increases in energy efficiency.

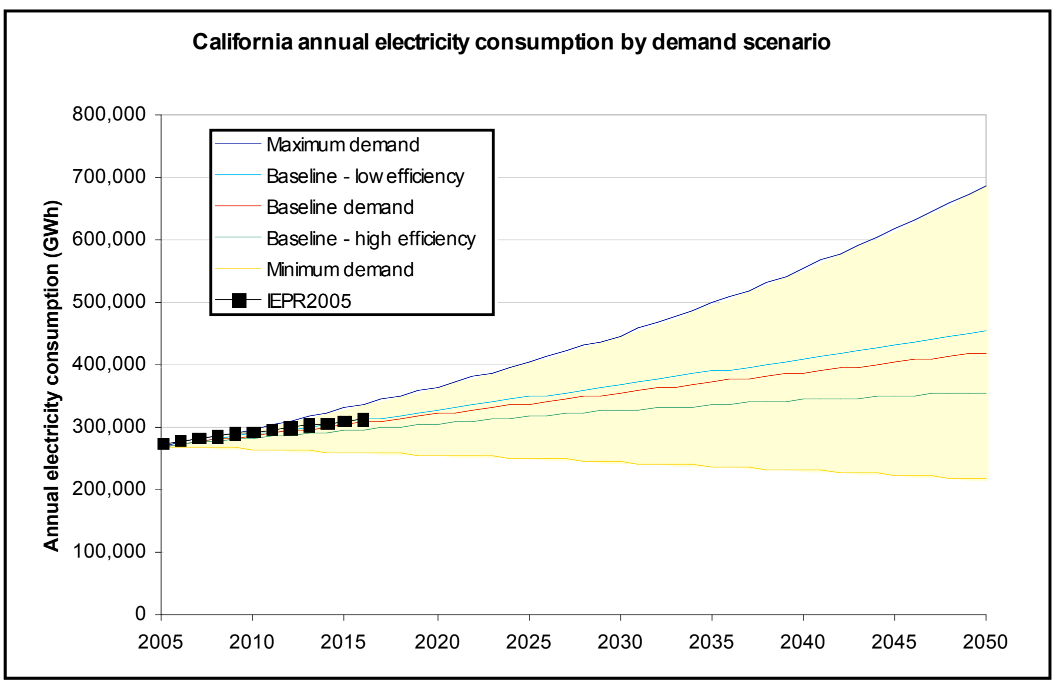


Figure 37 Annual electricity demand for each alternative scenario.

Per-capita electricity consumption (see Figure 38) is projected to increase an average of 0.63% annually in *Maximum demand*, to 9,836 kWh/year in 2050, and 0.24% per-year in *Baseline – low efficiency*, to 8,280 kWh/year. *Baseline - high efficiency* and *Minimum demand* see average annual reductions in per-capita electricity consumption of 0.29% and 0.94%, respectively, to 6,514 kWh/year and 4,853 kWh/year in 2050.

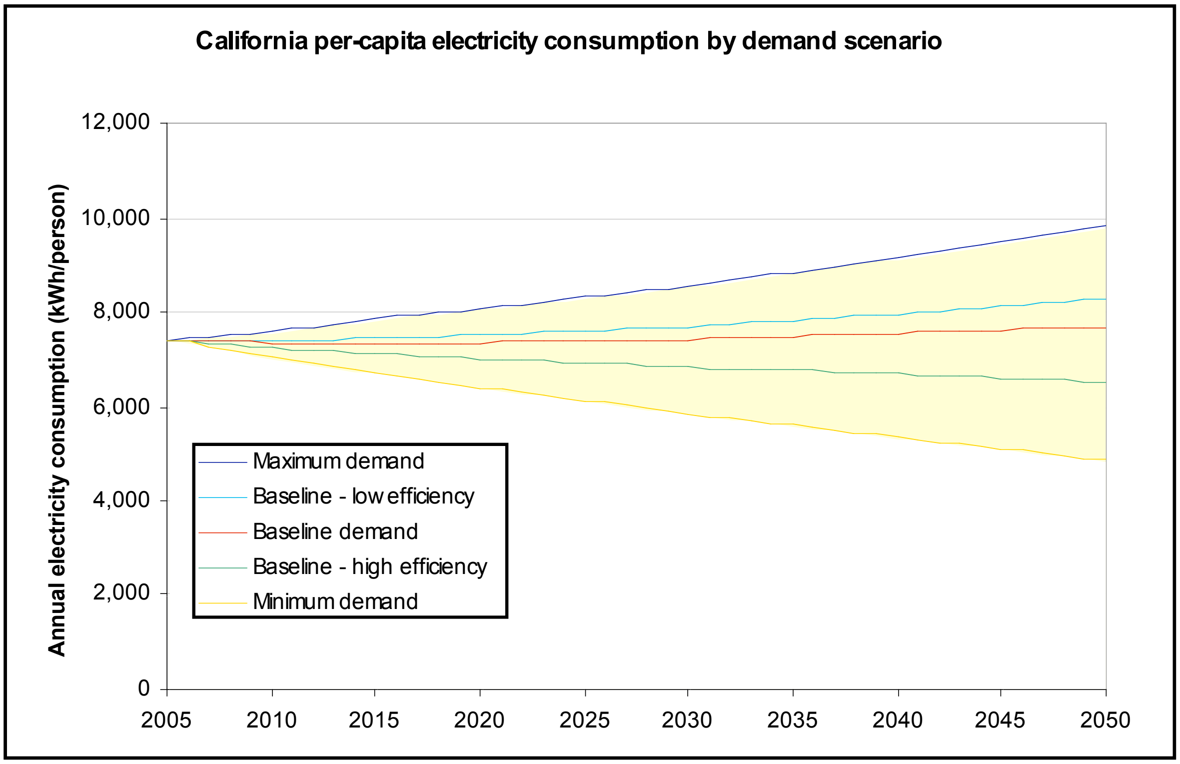


Figure 38 California annual per-capita electricity consumption by demand scenario.

8.2. Natural Gas Demands

Figure 39 shows natural gas demands in California for each of the alternative scenarios to 2050. Natural gas demand varies from 8,800 to 37,400 million therms in 2050. Much of the four-fold difference between the minimum and maximum scenarios, and the difference between *Maximum demand* and *Baseline – low efficiency,* can be attributed to the significant differences in industrial shipment assumptions that are linked to GSP growth. As shown by the electricity and natural gas demands in *Baseline – high efficiency* and *Baseline – low efficiency*, the impact of the most aggressive efficiency improvements is relatively small without being coupled to changes in population and economic growth.

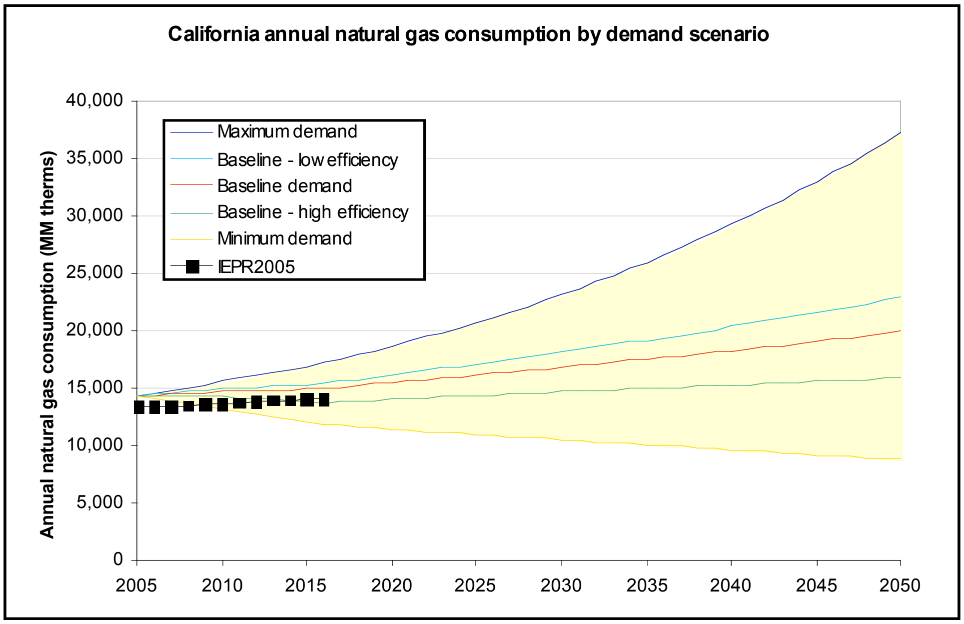


Figure 39 Annual natural gas demand for each alternative scenario.

Per-capita natural gas consumption is illustrated in Figure 40 for the alternate scenarios. In the baseline scenario, year 2050 per-capita consumption is 8% below current levels. *Minimum demand* sees a 50% reduction in per-capita consumption by 2050, while in *Maximum demand*, consumption increases 35% per-capita by 2050. *Baseline – low efficiency* and *Baseline – high efficiency* see an increase in per-capita consumption of 6% and a reduction of 26%, respectively, by 2050. These sensitivity-scenarios illustrate the range of efficiency assumptions included in the natural gas projections.

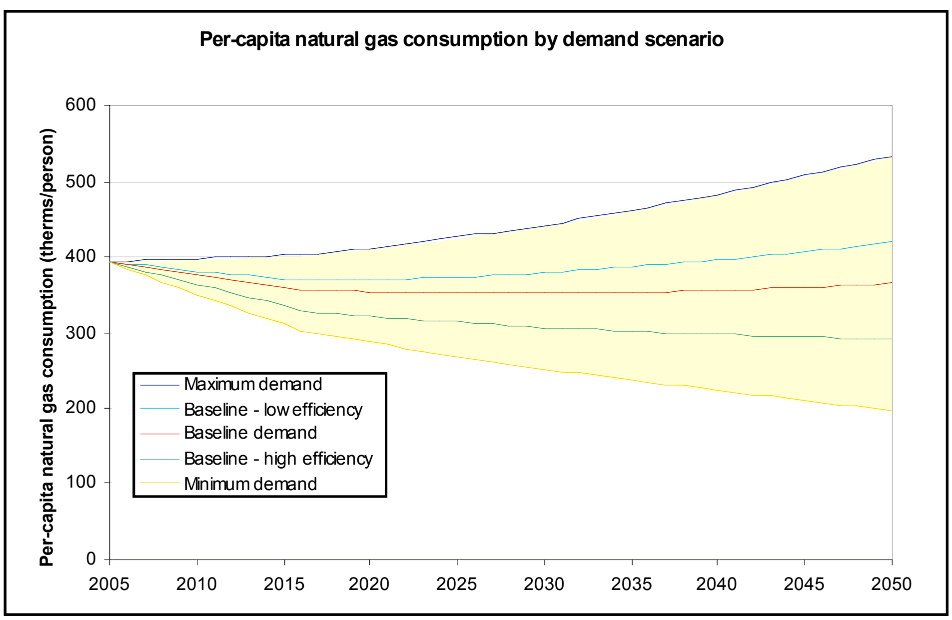


Figure 40 Per-capita natural gas consumption for each alternative scenario.

8.3. Transportation Fuel Demands

Figure 41 and Figure 42 show the transportation fuel demand and per-capita fuel demand in California for each of the alternative scenarios out to 2050. Also shown on Figure 41 is the IEPR2005 fuel demand projection to 2025, which is matched and extended to 2050 in the baseline scenario. The key drivers for transportation fuel demand are population, vehicle miles traveled per-capita, fuel economy, and sales distribution by vehicle type. Transportation fuel shows the most significant variation between the highest and lowest demands of any of the three energy demands, in part because of the significant reductions assumed possible in *Minimum demand*. The fuel demand reduction is dependent upon very large vehicle efficiency improvements that were assumed possible for light-duty vehicles and an assumed significant decline in travel demand. Out of the seven-fold change in demand between the extreme scenarios for light-duty vehicles (six-fold for total fuel usage including heavy-duty and aircraft demand), the fuel economy and travel demand (VMT/capita) assumptions account for approximately a factor of four.

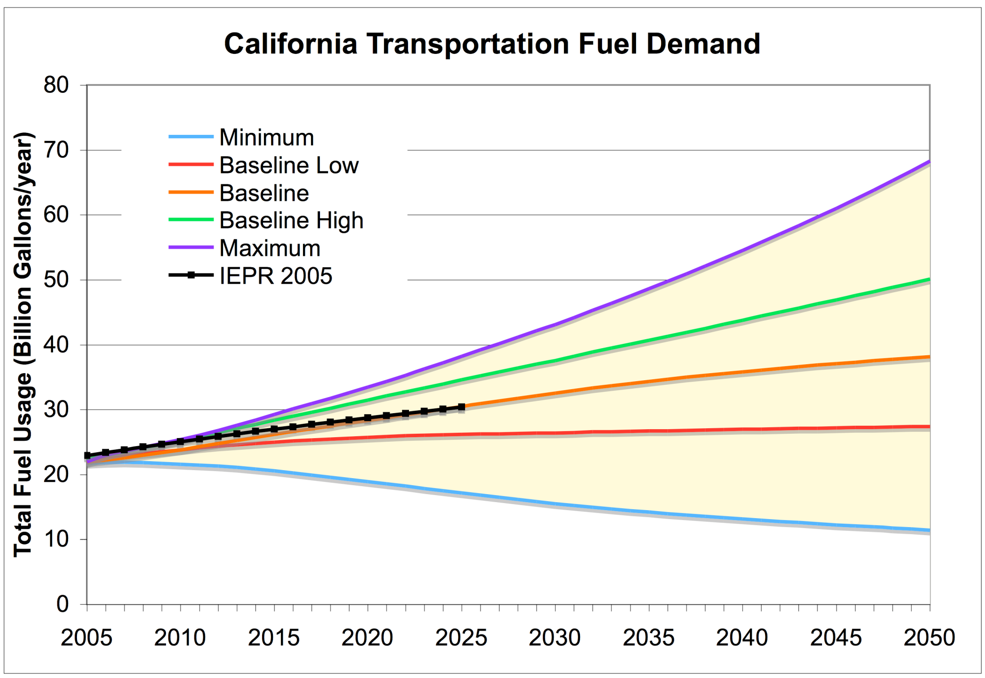


Figure 41 Annual transportation fuel demand for each alternative scenario.

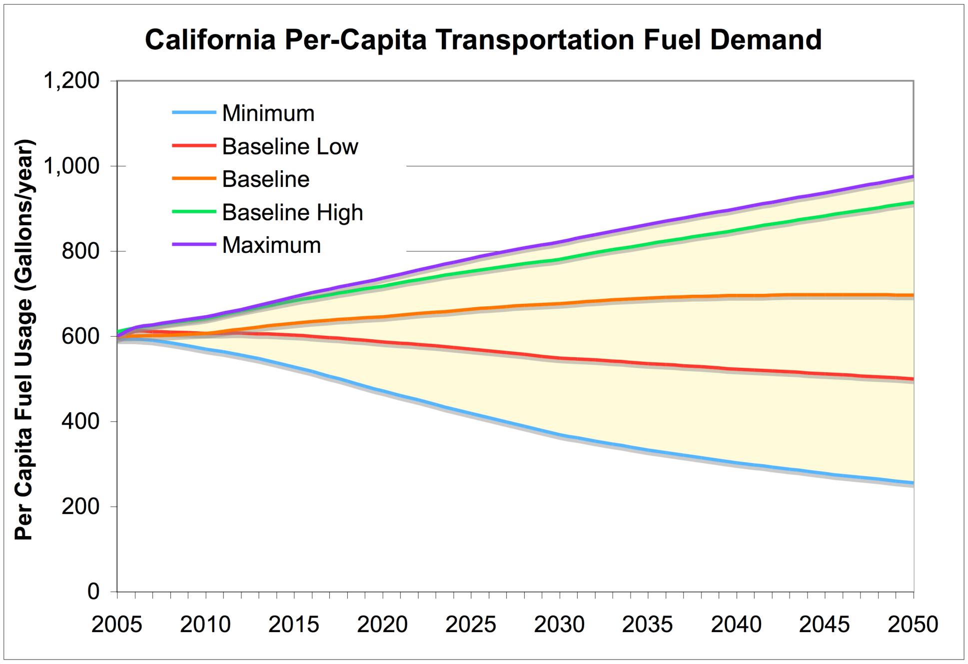


Figure 42 Annual per-capita transportation fuel demand for each alternative scenario.

9. REFERENCES

Argonne National Lab (2003). VISION Model: Description of Model Used to Estimate the Impact of Highway Vehicle Technologies and Fuels on Energy Use and Carbon Emissions to 2050. Argonne report: ANL/ESD/04-1. December.

CEC (1996) CalCars: The California Conventional and Alternative Fuel Response Simulator. Chris Kavalec. California Energy Commission.

CEC (2003a) California energy demand 2003-2013 forecast. California Energy Commission, 100-03-002SD, February 11.

CEC (2003b) Output files from CEC model CalCars. Received via email from Transportation Office, 5/12/2006.

CEC (2003c) FUTURES Model. Spreadsheet model developed by TIAX. Received via email from Transportation Office, 5/12/2006.

CEC (2003d) 2003 Integrated Energy Policy Report. California Energy Commission, Pub No. 100-03-019, December.

CEC (2003e) 2003 Integrated Energy Policy Report Subsidiary Volume: Transportation Fuels, Technologies and Infrastructure Assessment Report. California Energy Commission, Pub No. 100-03-013F, December.

CEC (2005a) California energy demand 2006-2016: Staff energy demand forecast (Revised September 2005). California Energy Commission, CEC-400-2005-034-SF-ED2, September.

CEC (2005b) Energy demand forecast methods report. California Energy Commission, CEC-400-2005-036, June.

CEC (2005c) Options for energy efficiency in existing buildings. California Energy Commission, CEC-400-2005-039-CMF, December.

CEC (2005d) 2005 Integrated Energy Policy Report. Commission Final Report. CEC-100-2005-007-CMF. November.

CEC (2005e) Forecasts of California transportation energy demand, 2005-2025 (In support of the 2005 Integrated Energy Policy Report). California Energy Commission, CEC-600-2005-008, April.

EIA (2006) Annual energy outlook 2006 with projections to 2030. Report #:DOE/EIA-0383(2006), Energy Information Administration, U.S. Department of Energy, February. http://www.eia.doe.gov/oiaf/aeo/

DOF (2004) Population projections by race/ethnicity for California and its counties 2000-2050. State of California, Department of Finance, Sacramento, CA, May. http://www.dof.ca.gov/HTML/DEMOGRAP/DRU_Publications/Projections/P1.htm

DOF (2006) E-5 population and housing estimates for cities, counties, and the State, 2001-2006, with 2000 benchmark. State of California, Department of Finance, Sacramento, CA, May. http://www.dof.ca.gov/HTML/DEMOGRAP/ReportsPapers/Estimates/E5/E5-06/E-5text2.asp

Ghanadan, Rebecca and Jonathan Koomey (2005). Using energy scenarios to explore alternative energy pathways in California. *Energy Policy* 33 (2005) 1117–1142.

Itron, Inc; KEMA, Inc.; RLW Analytics, Inc.; and Architectural Energy Corp (2006) California energy efficiency potential study, volume 1. CALMAC Study ID: PGE0211.01, submitted to Pacific Gas & Electric, May 24. Available online at: http://www.calmac.org/

KEMA, Inc. (2006) California industrial existing construction energy efficiency potential study. Prepared for Pacific Gas and Electric Company, CALMAC Study ID: PGE0252.01, May.

Landis JD and Michael Reilly (2003) How we will grow: Baseline projections of California's urban footprint through 2100. Working Paper 2003-2004, Department of City and Regional Planning, Institute of Urban and Regional Development, University of California-Berkeley, Berkeley, CA.

McCarthy R, Yang C, and Joan Ogden (2006) California baseline energy demands to 2050 for Advanced Energy Pathways. Prepared for the Advanced Energy Pathways project of the California Energy Commission, June.

Mintzer I, Leonard A, Harris G, and Napier Collyns (2006) Clean cars and clean fuels for California: Scenarios of advanced vehicle and alternative fuel development in the Golden State. Prepared for the Advanced Energy Pathways project of the California Energy Commission, April.

Nexant (2005) Hydrogen Delivery Infrastructure Option Analysis. Presentation at the DOE and FreedomCAR & Fuel Partnership Hydrogen Delivery and On-Board Storage Analysis Workship. January 2005.

Quantum Consulting, Inc./Itron Inc. (2006) California residential sector electricity model, Version 5. Received via email, March 29.

USCB (2001) 2002 NAICS and 1987 SIC correspondence tables. U.S. Census Bureau. Available at: http://www.census.gov/epcd/naics02/

USGBC (2005) LEED-NC: Green building rating system for new construction & major renovations, Version 2.2. U.S. Green Building Council, October. https://www.usgbc.org/ShowFile.aspx?DocumentID=1095

APPENDIX

A. Electricity sector regional classifications

Projections for the residential sector are disaggregated in terms of California's 16 climate zones (based upon the CEC's climate zone definitions for energy forecasts, rather than those used in the Title 24 Building Standards), which divide the state into regions with similar weather patterns. The remaining sectors are disaggregated according to utility planning areas defined by the CEC (CEC, 2005b). Figure A-1 outlines the climate zones for California, and the utilities comprising each of the electricity planning regions are summarized in Table A-1 (refer to Table 3for the relationship between climate zones and electricity and natural gas utility planning areas).

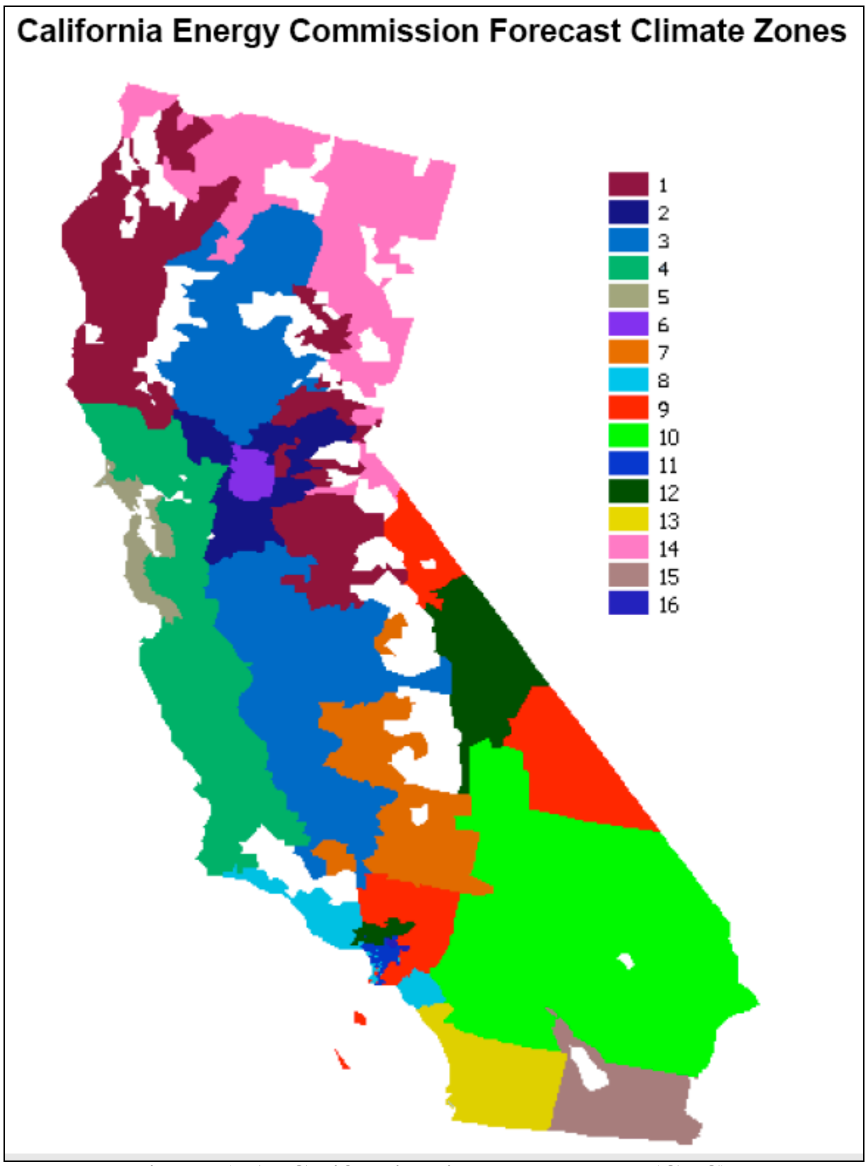


Figure A-1. California climate zone map (CEC).

Table A-1. Description of planning areas used in projections (CEC, 2005a).

Planning area	Utilities included		
Pacific Gas and Electric (PG&E)	PG&E Alameda Biggs Calaveras Gridley Healdsburg Lassen MUD Lodi	Lompoc Merced Modesto Palo Alto Plumas – Sierra Redding Roseville	San Francisco Shasta Silicon Valley Tuolumne Turlock Irrigation District Ukaih USBR-CVP
Sacramento Municipal Utility District (SMUD)	SMUD		
Southern California Edison (SCE)	Anaheim Anza Azusa Banning	Colton MWD Riverside SCE	Southern California Water USBR-Parker Davis Valley Electric Vernon
Los Angeles Department of Water and Power (LADWP)	LADWP		
Cities of Burbank, Glendale, and Pasadena (BGP)	Burbank	Glendale	Pasadena
Other planning areas (*Other*)	Pacificorp Sierra Pacific	Surprise Valley Truckee-Donner	Imperial Irrigation District
Department of Water Resources (DWR)	DWR		

B. Transportation fuel demand scenario modelling

A vehicle stock turnover model tracks the age distribution and other characteristics of interest for a population of vehicles (e.g. light-duty vehicles). To project vehicle fuel requirements into the future, the vehicle characteristics of interest such as vehicle miles traveled (VMT) and fuel economy in miles per gallon (MPG) for a number of different vehicle body types (classes) and power trains (e.g. conventional gasoline, hybrid, diesel) are tracked. The alternate scenarios use a vehicle stock turnover model as an accounting framework and do not endogenously predict vehicle MPG, VMT or fuel usage. Total fuel usage under these alternative scenarios are driven by exogenous inputs that describe the trajectory out to 2050 of total state population, average VMT/capita, vehicle sales/person and vehicle fuel economy. Projections and extrapolations for these parameters are based upon CEC models (CalCARS and Futures models), considerations of potential policy regulations, and a literature review of other vehicle scenarios for California.

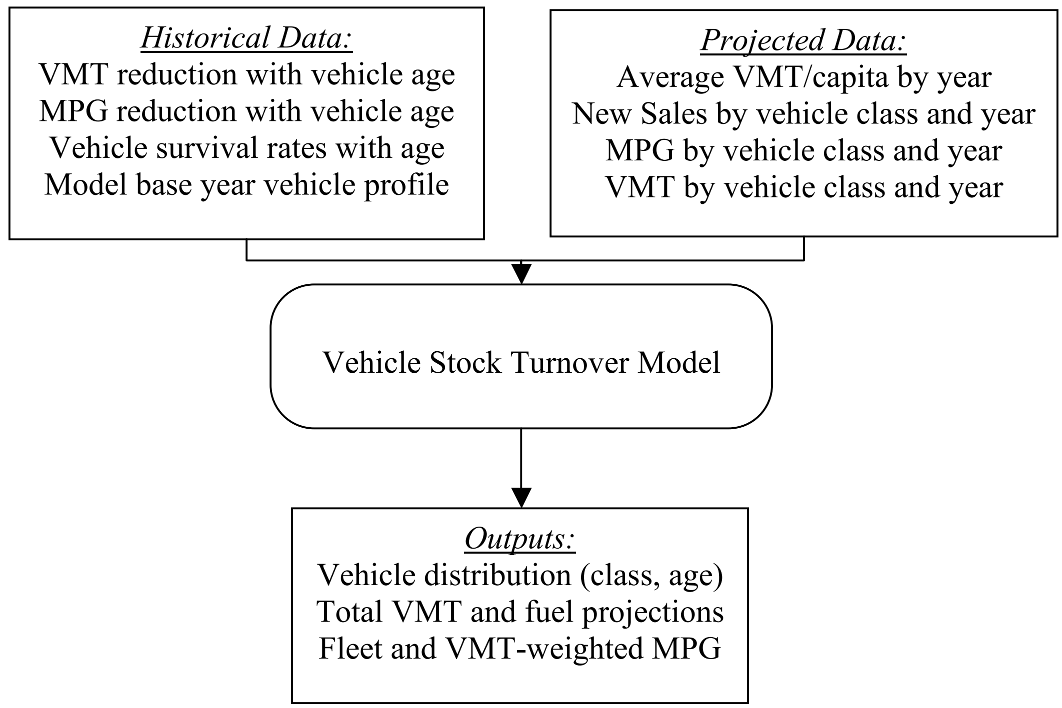
B.1. Outputs

Each of the scenarios is described in a separate Microsoft Excel workbook. The *Summary* sheet in each workbook provides the number of vehicles, total VMT, VMT-weighted fuel economy, and fuel requirements for three broad classes of vehicles (conventional gasoline, hybrids and diesels) for each of the model years (2003-2050). These are summed to get the total number of light duty vehicles (LDVs), VMT, and gasoline and diesel demands for the State. Added to these numbers are projected fuel demands for non-light duty vehicles. Ethanol demand is calculated based upon a 5.7% by volume oxygenate additive for all gasoline over the entire model period. This sheet provides state-wide annual totals for these parameters with no spatial disaggregation. The model also provides monthly fuel demands for the model years in one sheet (*Monthly*).

B.2. Methods

Model framework
The vehicle stock turnover model (VSTM) is implemented in Microsoft Excel and run in Visual Basic. VSTM tracks the age distribution (from new to 25 years old) for 15 different classes of vehicles (as defined in CALCARS 2005) for three powertrain options (for a total of 45 distinct vehicle types). The model tracks these vehicle populations (age and distribution) over the 2003-2050 timeframe and determines the overall vehicle populations, fleet VMT, fleet VMT-weighted fuel economy, and total fuel requirements (gasoline and diesel) for all years.

Model diagram



Input requirements and model relationships

For each alternate scenario, there are a number of required exogenous data inputs for the model to accurately track and project vehicle age and class distribution:

1) For a historical base year (2003), the existing vehicle population is characterized in terms of total number of vehicles and age distribution (CALCARS Input) **Sheet("2003_Vintage")**
2) Annual state population
3) New sales data for each projection year by vehicle class **Sheet("Car_Sales")**
    a. Sales data is determined by several factors in the alternative scenarios
        i. Annual average vehicle sales per person
        ii. Annual sales distribution of 45 model types
4) MPG of new vehicles for each projection year by vehicle class **Sheet("MPG")**
    a. Vehicle fuel economy is determined by several factors in the alternative scenarios
        i. Distribution of vehicle fuel economy among the 45 vehicle classes in the model base year (2003)
        ii. Annual average fuel economy based upon the base year fleet distribution
5) VMT for each projection year by vehicle class **Sheet("VMT_yr")**
    a. VMT per vehicle is determined by several factors in the alternative scenarios
        i. Annual average VMT/capita input
        ii. Baseline scenario VMT distribution for all 45 vehicle classes

Also required for the stock turnover model are the following important relationships:

6) VMT reduction for vehicles by age (from EMFAC) **Sheet("VMT_Decay")**
7) Car and truck survival rates as a function of age (from EMFAC) **Sheet("Veh_Survival")**
8) MPG reductions as a function of age (assume to be constant)
9) Monthly fuel demand as a percentage of annual demand (from EIA CA Petroleum data) **Sheet('Monthly')**

CalCARS determines these relationships endogenously as a central part of the model since consumer choices about vehicles and transport modes will affect vehicle retirements as well as VMT profiles. These historical relationships were extracted from the EMFAC model (for use in the CEC's Futures model) and assumed to apply into the future.

The transportation office has provided CalCARS output files for various model runs based upon three gasoline price scenarios (Lower, Higher and Highest) and two GHG policy environments (Pavley and no Pavley regulations). The baseline scenario was based upon the CEC projections from CalCARS model runs for (2) New Sales, (3) new vehicle MPG and (4) new vehicle VMT based upon the middle (called "Higher") gasoline price and no GHG policy (i.e. no Pavley regulations) scenario.

The alternative scenarios are based upon a collection of data inputs and critical relationships that are used as inputs to the Vehicle Stock Turnover Model (VSTM) that are used to describe a series of possible fuel demand trajectories from a number of different sources and input assumptions.

<u>Assumptions</u>
- Car/truck ratio
- VMT/capita
- Vehicle sales/person
- MPG
- Population is taken from the Department of Finance projections.

The historical relationships for VMT reductions as a function of vehicle age and vehicle survival are derived from the EMFAC model using data from the 1998 model year. The data were extracted and the relationships were modeled using a power law function and a generalized logistic curve, respectively. The equation parameters were solved to fit these equations to the model data. Because VMT/capita is one of the major input assumptions for the model, while VMT/vehicle is what is determined by the EMFAC VMT equation, it was necessary to introduce a correction factor that modified the VMT decay equation to account for changes in vehicles/capita that would accompany changes in vehicle sales. The VMT decay was modified to take into account the change in vehicles/person and scale the VMT decay curve accordingly. It is assumed that these VMT reduction equations apply to each type of vehicle drivetrain (conventional, hybrids and diesels) and class (compacts, sedans, trucks, etc), and hold into the future as well. No reduction in vehicle fuel economy is assumed as a function of age. Monthly historical data for California transportation fuel demands is also included to predict how the total fuel requirements will be distributed amongst the various months of the year.

Important worksheets

VSTM – This sheet is the main worksheet for the vehicle stock turnover model (VSTM). It shows the numbers of vehicles in each of the years, from age 0 to 25. For each year of the projection period, the model displays the total number of LDVs, and the total VMT and fuel economy for each vehicle type, age, and year. It then calculates, based upon these factors, the total fuel usage (gallons of gasoline equivalent) on an annual basis for the entire model period for that population of vehicles. To account for vehicle retirements and VMT reductions as a function of vehicle age, an empirical relationship is used, based upon data from the CARB's EMFAC model. This sheet looks up a number of inputs from other model worksheets. The sheet models only one vehicle class at a time, and when the model year is varied between 2003 and 2050, the sheet calculates the total number of vehicles, VMT, MPG and fuel usage for that vehicle. Running a macro will activate the model, which iterates through each model year and all the vehicle classes, and records the results into the **Results1** sheet. If the input parameters are not changed, there is no need to re-run the model.

Car_Sales – This sheet describes the total number of vehicles sold in each year throughout the scenario, broken down by vehicle class (45 types). For the alternate scenarios, the key inputs are population, annual vehicle sales per person, and the distribution of vehicle sales by class. Each of these inputs is determined exogenously. The distribution of vehicle sales by vehicle class was determined for the alternative scenarios by comparing the fuel economy of each vehicle type to the average, and using the difference as a means for scaling the numbers of vehicles. For example, if the subcompact was 30% more fuel efficient than average, while the large SUV was 25% less fuel efficient, one scenario could change the distribution of vehicles by this amount, making the prevalence of subcompacts 30% higher than the baseline, while the large SUV was 25% less prevalent than in the baseline scenario.

MPG – This sheet describes the fuel economy of all 45 vehicle types for each of the model years. For the alternative scenarios, the fuel economy of each vehicle class in the base year is scaled by a multiplier to account for improvements in car and light truck fuel economy. This multiplier is exogenously determined in the scenario development as an annual trajectory, which is similar to tightening fuel economy standards for cars and light trucks.

VMT_yr – This sheet describes the annual unadjusted VMT per vehicle for different classes and for each year of the scenario. The values for each of the vehicles are adjusted due to the changes in the number of vehicles sold per person. Since VMT/capita is a major driver for the scenarios, VMT/vehicle needs to be adjusted as vehicles/person changes. The VMT/capita profile is defined exogenously for each of the scenario years. The baseline scenario allocation of VMT between all of the various vehicle types is maintained, but scaled by the ratio of VMT/capita between the baseline and the alternate scenarios.

VSTM_ALL – This sheet tallies up the VMT for each of the model years. It is used to correct the VMT numbers by modifying the VMT decay function so as to account for changes in the numbers of vehicles sold/capita. This sheet should not be modified.

Temporal Disaggregation

Once the model provides annual fuel demand, it may still be necessary to estimate the seasonal, weekly and hourly distribution of fuel demand because the distribution of demand is not constant over the months of the year, days of the week, and hours of the day. The variation can affect the scale and storage requirements for production/refining, distribution and fueling infrastructure. The CEC does not track fuel demand at a finer temporal scale than annual demand. Other data sources are relied upon to provide average demand profiles which can be applied to the annual total. Monthly fuel demand data for California is based upon EIA historical data. Eleven years of diesel fuel demand and 22 years of gasoline demand is averaged to calculate the average fraction of annual demand that falls in a given month. This monthly profile (i.e., percent of annual total in each month) is multiplied by the projected annual demands to estimate monthly demand for any month to 2050.

A daily and hourly profile was obtained for a representative refueling station for a representative week. This profile was used to calculate the fraction of weekly demand that occurs each hour of the week. This profile can then be applied to the monthly demands by assuming that each week of the month has an identical fuel demand profile.

B.3. Baseline and Alternative Scenario Vehicle Classes

1. Subcompact Car
2. Compact Car
3. Midsize Car
4. Large Car
5. Sport Car
6. Small X-Utility Car
7. Small X-Utility Truck
8. Midsize X-Utility
9. Compact SUV
10. Midsize SUV
11. Large SUV
12. Compact Van
13. Standard Van
14. Compact Pickup Truck
15. Standard Pickup Truck

B.4. Files, data sources, and further methodology description

'2003 Vehicle Fleet Information v2.xls' Obtained from MWG – Describes the 2003 residential, commercial and rental fleets for 15 different classes of vehicles, broken down by age from 1-16 years old as well as 17+ years old. This is a better set of values than the 2003 total vehicle stock given in FUTNGHG2. This was used to provide the data for the sheet 2003_Vintage in **AEP-BaselineScenario-Fuel.xls**. The vehicles that are in the 17+ age bracket were linearly distributed among the 17-25 year old bracket to match the data up with the 25 age classes for the model.

VMT_Decay – Based upon data from CEC/TIAX FUTURES model, which comes from the EMFAC model (CARB). The data is plotted and used to fit parameters for a power-law function. These parameters are then used to calculate the percentage of initial VMT for each year of the vehicles lifetime (up to 25 years).

$$\%VMT = 1 - 0.073(Age)^{0.6}$$

This sheet also includes data from the VISION model, though this data shows a very different VMT profile as a function of age and is not used.

Veh_Survival - Based upon data from CEC/TIAX FUTURES model, which comes from the EMFAC model (CARB). The vehicle survival profile data is plotted and used to fit parameters for a generalized logistic curve function. These parameters are used to calculate the percent of existing vehicles lost each year as a function of age. The sheet also includes data from the VISION model but this data shows a much faster rate of vehicle retirement than the EMFAC model and this data is not used.

B.5. Assumptions for Scenarios:

Minimum demand

Population – The scenario is based upon the low population projection.

Vehicle sales per person – This is based upon a decline in vehicle sales per person from 4.1% in 2004 to 3.1% in 2050.

VMT per capita – VMT per capita declines from 8132 in 2004 to 5887 by 2050. The 2050 value is approximately equal to the year 2000 US average VMT per capita and the scenario assumes that California's VMT/capita declines linearly to this value by 2050.

Vehicle distribution – Conventional drivetrains decline from 98.5% to 20% by 2050 while hybrids and diesels each achieve 40% of the market by 2050. The distribution of the 15 different car classes in 2050 is altered based on the fuel economy of an individual class compared to the fleet average. In this high efficiency scenario, those vehicle classes that are on average more efficient are purchased more frequently than those that are less efficient on average. The amount of change in purchase behavior compared to the baseline is proportional to the deviation from average fuel economy. This results in vehicle sales of 69% cars and 31% trucks in 2050 compared to approximately 50% - 50% car truck ratio in 2003.

MPG – The scenario assumes fuel economy trajectory for cars and light trucks that tracks the Pavley standards (assuming no alternative fuels are introduced) to 2016 and then assumes half the rate of annual increase in average fuel economy out to 2050. This yields an average car fuel economy of 65.4 mpg and a light truck fuel economy of 41.2 mpg.

Baseline – low demand

Population – The scenario is based upon the baseline population projection.

Vehicle sales per person – This assumption is based upon the baseline vehicle sales per person, which reaches 5.97% in 2025 and remains constant to 2050.

VMT per capita – VMT per capita remains constant at the 2004 level of 8132 miles/person until 2050.

Vehicle distribution – Conventional drivetrains decline from 98.5% to 33% by 2050 while hybrids and diesels each achieve 33% of the market by 2050. The distribution of the 15 different car classes in 2050 is altered based on the fuel economy of an individual class compared to the fleet average. In this scenario, those vehicle classes that are on average more efficient are purchased more frequently than those that are less efficient on average. The amount of change in purchase behavior compared to the baseline is proportional to the deviation from average fuel economy. This results in vehicle sales of 59% cars and 41% trucks in 2050 compared to approximately 50% - 50% car truck ratio in 2003.

MPG – The scenario assumes fuel economy trajectory for cars and light trucks that achieves the 2016 Pavley standards (assuming no alternative fuels are introduced) by 2050. This is a moderate efficiency case that yields an average car fuel economy of 43.3 mpg and a light truck fuel economy of 30.7 mpg.

Baseline – high demand
Population – The scenario is based upon the baseline population projection.

Vehicle sales per person – This assumption is based upon the baseline vehicle sales per person, which reaches 5.97% in 2025 and remains constant to 2050.

VMT per capita – VMT per capita is based upon the baseline VMT/capita profile, which reaches 10,833 miles/person in 2050.

Vehicle distribution – Conventional drivetrains remain quite prevalent declining from 98.5% to 70% by 2050 while hybrids achieve 10% and diesels achieve 20% of the market by 2050. The distribution of the 15 different car classes in 2050 is altered based on the fuel economy of an individual class compared to the fleet average. In this low efficiency scenario, those vehicle classes that are on average less efficient are purchased more frequently than those that are more efficient on average. The amount of change in purchase behavior compared to the baseline is proportional to the deviation from average fuel economy. This results in vehicle sales of 39% cars and 61% trucks in 2050 compared to approximately 50% - 50% car truck ratio in 2003.

MPG – The scenario assumes a low fuel economy trajectory for cars and light trucks that tracks the baseline. This yields an average car fuel economy of 31.6 mpg and a light truck fuel economy of 28.7 mpg by 2050.

Maximum demand
Population – the scenario is based upon the high population projection

Vehicle sales per person – This is based upon an increase in vehicle sales per person from 4.1% in 2004 to 8.2% in 2050.

VMT per capita – VMT per capita increases from 8132 in 2004 to 12,942 by 2050.

Vehicle distribution – Conventional drivetrains remain quite prevalent declining from 98.5% to 80% by 2050 while hybrids achieve 10% and diesels achieve 10% of the market by 2050. The distribution of the 15 different car classes in 2050 is altered based on the fuel economy of an individual class compared to the fleet average. In this low efficiency scenario, those vehicle classes that are on average less efficient are purchased more frequently than those that are more efficient on average. The amount of change in purchase behavior compared to the baseline is proportional to the deviation from average fuel economy. This results in vehicle sales of 39% cars and 61% trucks in 2050 compared to approximately 50% - 50% car truck ratio in 2003.

MPG – The scenario assumes a low fuel economy trajectory for cars and light trucks that matches the baseline scenario. This yields an average car fuel economy of 31.6 mpg and a light truck fuel economy of 28.7 mpg by 2050.

C. GBN scenarios

We model electricity and natural gas demands for the GBN scenarios based on their stated population and GSP projections, and using demographic, economic, and efficiency assumptions described previously for the AEP demand scenarios. Table A-2 lists the assumptions underlying the GBN scenario demographic and economic projections, and compares them to the range of assumptions in the AEP scenarios. The ranges captured in the GBN scenarios for households, floorspace, and shipments are tighter than for the range of AEP scenarios. This contributes significantly to the smaller range among GBN scenarios energy demand projections.

Table A-2. Comparison of AEP and GBN scenario demographic and economic assumptions and projections.

	People get smarter	State of fear	Too little, too late	AEP minimum	AEP baseline	AEP maximum
Population (millions)						
2025	48.08 (31%)	44.60 (22%)	45.94 (26%)	40.99 (12%)	45.93 (26%)	48.79 (33%)
2050	64.72 (77%)	50.15 (37%)	41.56 (14%)	44.77 (22%)	54.78 (50%)	70.00 (92%)
SFHH share (%)						
2025	61.5% (-11%)	72.1% (4%)	69.9% (1%)	65.7% (-5%)	69.0% (0%)	73.1% (6%)
2050	55.3% (-20%)	74.4% (8%)	71.2% (3%)	63.0% (-9%)	69.0% (0%)	77.3% (12%)
Avg. PPH						
2025	3.12 (5%)	2.83 (-4%)	2.96 (0%)	3.12 (5%)	2.96 (0%)	2.83 (-4%)
2050	3.33 (13%)	2.65 (-10%)	2.96 (0%)	3.33 (13%)	2.96 (0%)	2.65 (-10%)
SFHH (millions)						
2025	9.27 (11%)	11.13 (33%)	10.68 (28%)	8.44 (1%)	10.67 (28%)	12.35 (48%)
2050	10.50 (26%)	13.73 (64%)	9.81 (17%)	8.27 (-1%)	12.93 (55%)	19.92 (138%)
MFHH (millions)						
2025	5.81 (53%)	4.33 (14%)	4.62 (21%)	4.44 (16%)	4.61 (21%)	4.56 (20%)
2050	8.50 (123%)	4.73 (24%)	3.99 (5%)	4.87 (28%)	5.26 (38%)	5.85 (54%)
Floorspace (MM ft^2)						
2025	8,277 (36%)	7,686 (27%)	7,917 (30%)	7,063 (16%)	7,915 (30%)	8,408 (38%)
2050	11,991 (97%)	9,291 (53%)	7,701 (27%)	8,295 (37%)	10,149 (67%)	12,969 (114%)
GSP (billion 2000$)						
2025	$2,543 (73%)	$1,932 (31%)	$2,352 (60%)	$1,768 (20%)	$2,531 (72%)	$3,050 (107%)
2050	$4,808 (227%)	$1,648 (12%)	$2,759 (88%)	$2,349 (160%)	$4,987 (239%)	$7,683 (422%)
SFGSP (%)						
2025	37.1% (-5%)	37.1% (-5%)	37.1% (-5%)	34.9% (-10%)	37.1% (-5%)	41.6% (7%)
2050	37.3% (-4%)	37.3% (-4%)	37.3% (-4%)	30.0% (-23%)	37.3% (-4%)	45.0% (16%)
Shipments (MM 2001$)						
2025	972 (65%)	738 (25%)	899 (53%)	636 (8%)	967 (64%)	1,307 (122%)
2050	1,846 (213%)	633 (7%)	1,059 (80%)	726 (23%)	1,914 (225%)	3,561 (505%)

* SFHH = single-family households; PPH = persons per household; MFHH = multi-family households; GSP = Gross State Product; SFGSP = shipments fraction of GSP

* Values in parentheses show percent compared to 2005.

We apply the efficiency assumptions described for the AEP projections to the GBN scenarios. *People get smarter* uses the high-efficiency assumptions from *Minimum demand* and *Baseline – high efficiency*, while *State of fear* and *Too little, too late* both adopt the baseline efficiency assumptions. Note that the efficiency assumptions we attribute to the GBN scenarios do not follow specifics from the narratives. Rather, we attempt to capture the general trends described using the efficiency assumptions we developed for the AEP projections.

Figures A-2 – A-4 illustrate our projections for annual electricity consumption, annual peak-hour electricity demand, and annual natural gas consumption based on the GBN scenario narratives. Each of the scenarios predicts demands that are less than in the AEP baseline scenario, and together, the GBN scenarios represent a much tighter range of future energy demand. Energy demands are lower in *People get smarter* than in *Baseline demand* due to higher efficiencies modeled for the GBN scenario. *State of fear* and *Too little, too late* see lower demands than the baseline due to lower activity levels (population and GSP). The smaller range in the GBN scenarios is a result of the tighter range in demographic, economic, and efficiency (no frozen efficiency case) assumptions, relative to those assumed for in the AEP scenario range. Also, while *Minimum demand* and *Maximum demand* fuse all of the best and worst assumptions, *State of fear* and *Too little, too late* combine lower efficiency assumptions (compared to *People get smarter*) with low activity levels. Consequently, the assumptions underlying the GBN scenarios balance out the energy demand projections and lead to the much tighter range relative to the AEP scenarios.

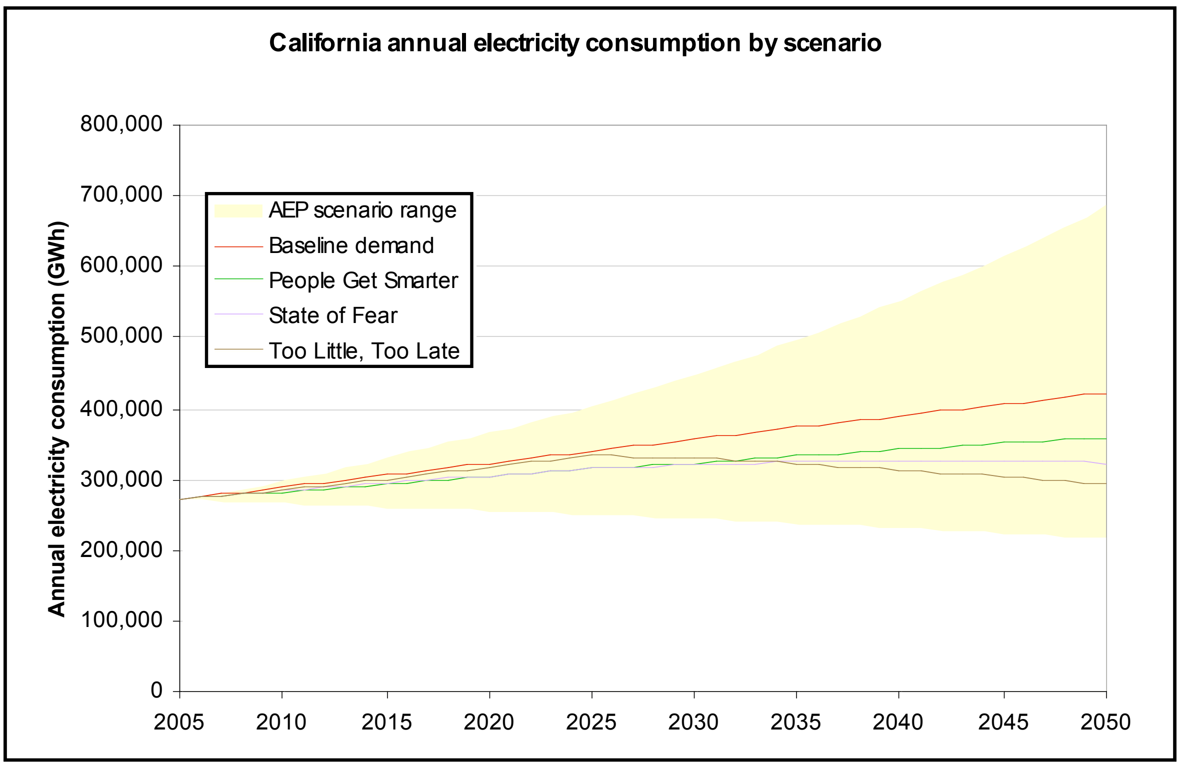


Figure A-2. California annual electricity demand (GBN scenarios).

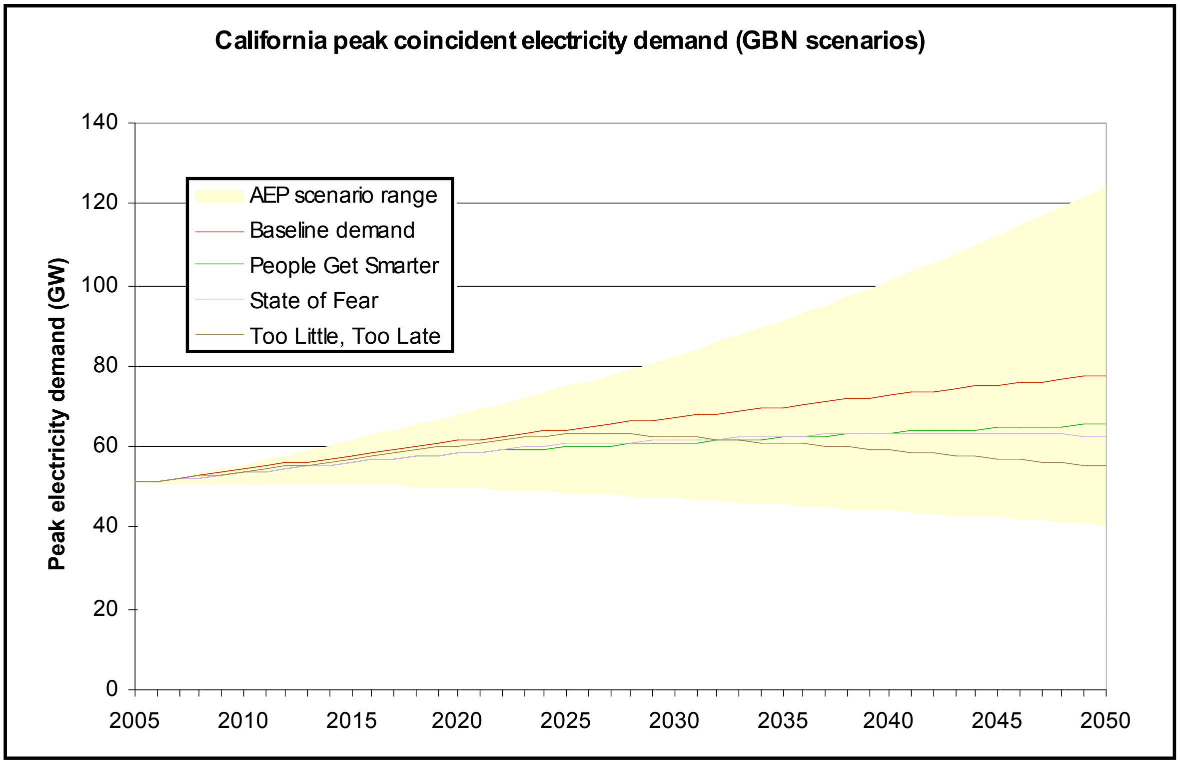


Figure A-3. California annual peak-hour electricity demand (GBN scenarios).

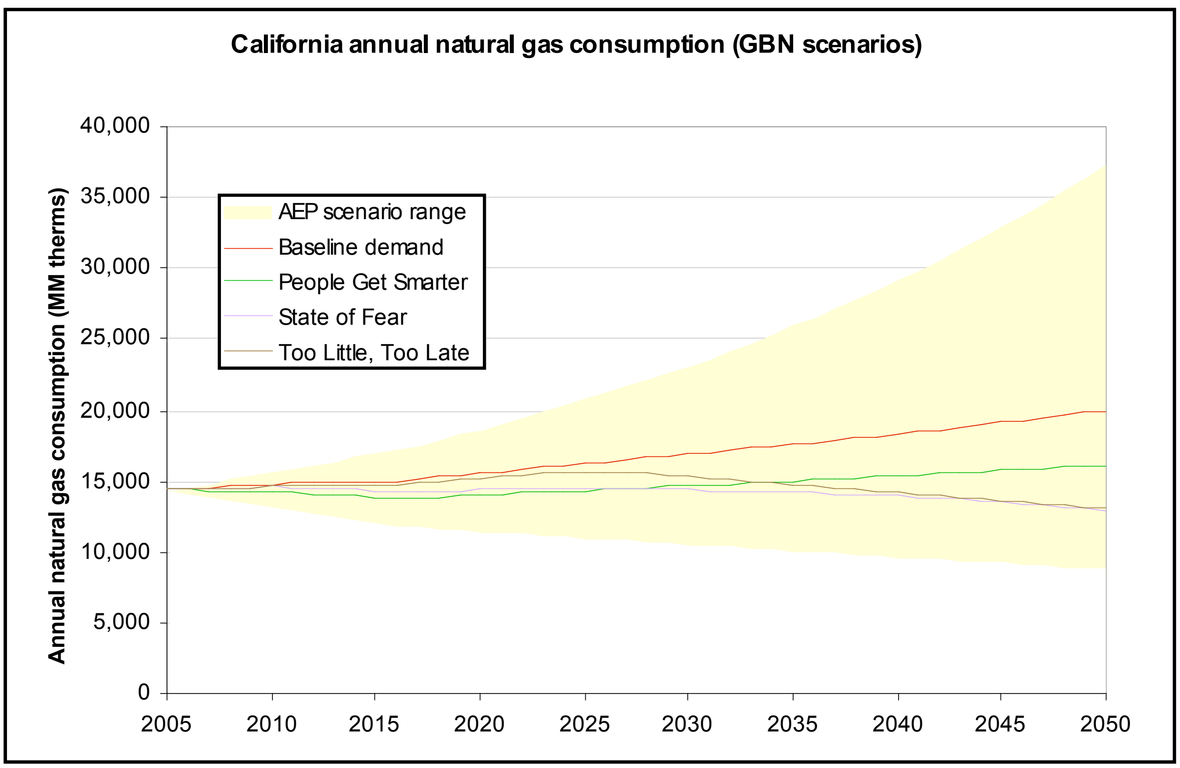


Figure A-4. California annual natural gas consumption (GBN scenarios).

Transportation fuel demands for the GBN scenarios are compared to the AEP demand scenarios in Figure A-5. GBN defined LDV fuel demand as part of the scenario report, and the trajectories illustrated in the figure are taken directly from their report.

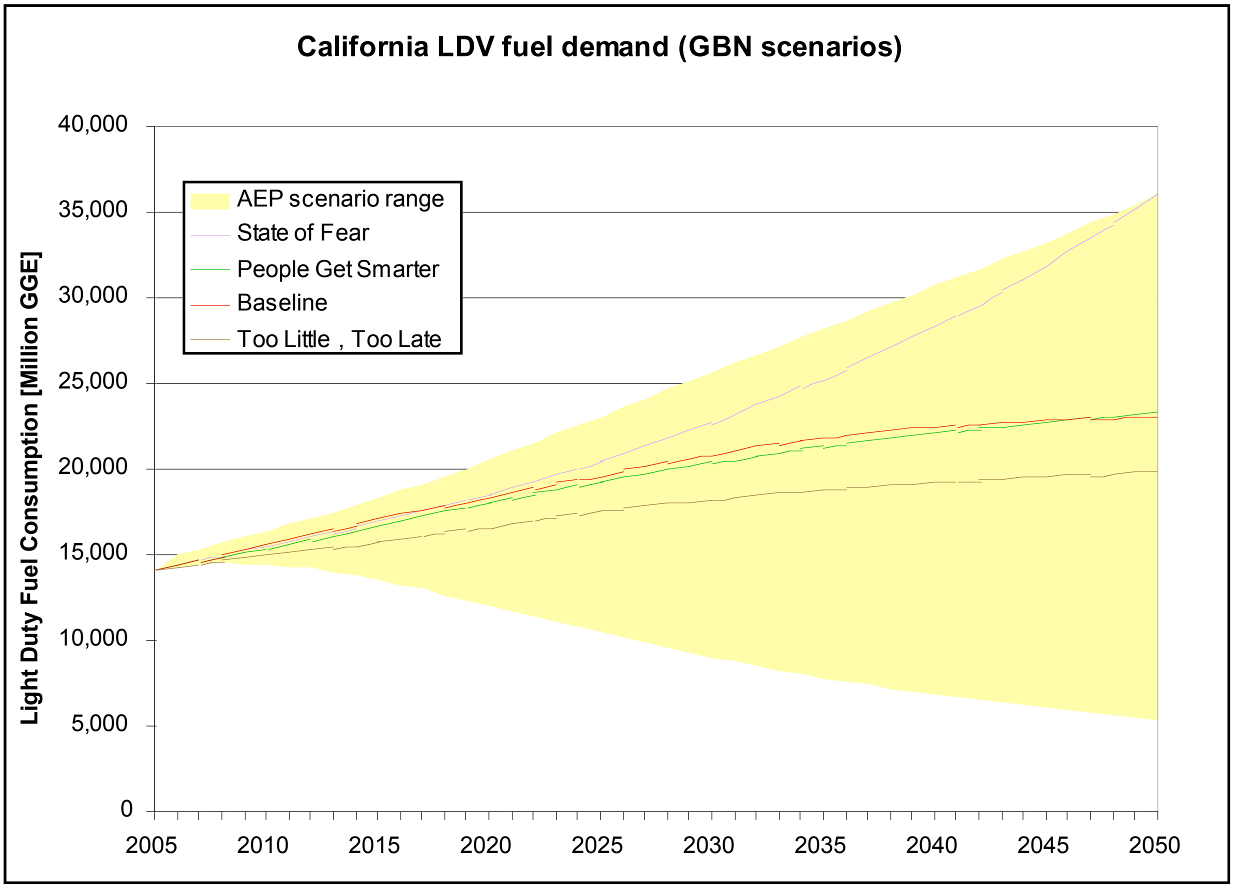


Figure A-5. California annual LDV fuel demand (GBN scenarios).

It is difficult to compare the GBN scenario projections to the AEP scenarios based on underlying assumptions. GBN projects fuel demand directly, based upon average annual growth rate assumptions, and it is difficult to pinpoint the exact demand drivers.

They also project VMT directly, based on assumed annual growth rates. The range of per-capita VMT for the GBN scenarios (9,240-12,942 in 2050) falls within the range of the AEP scenarios (5,583-12,916 in 2050), and bounds the AEP baseline scenario by ±20%, so presumably efficiency assumptions drive the difference in the range among scenarios. This is especially apparent in *State of fear*, which sees a 56% increase in fuel demand in 2050 compared to the AEP baseline, but only a 16% increase in per-capita VMT. But, it is not clear that the fuel demand and VMT are linked in the GBN scenarios, so it is difficult to discern the impacts of efficiency (and other drivers) on LDV fuel demand.