Arnold Schwarzenegger
Governor

ASSESSMENT OF LONG-TERM ELECTRIC ENERGY EFFICIENCY POTENTIAL IN CALIFORNIA'S RESIDENTIAL SECTOR

PIER PROJECT REPORT

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Preface

The Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The PIER Program, managed by the California Energy Commission (Energy Commission), conducts public interest research, development, and demonstration (RD&D) projects to benefit California's electricity and natural gas ratepayers. The PIER Program strives to conduct the most promising public interest energy research by partnering with RD&D entities, including individuals, businesses, utilities, and public or private research institutions.

PIER funding efforts are focused on the following RD&D program areas:

- Buildings End-Use Energy Efficiency
- Energy-Related Environmental Research
- Energy Systems Integration
- Environmentally Preferred Advanced Generation
- Industrial/Agricultural/Water End-Use Energy Efficiency
- Renewable Energy Technologies
- Transportation

In 2003, the California Energy Commission's Public Interest Energy Research (PIER) Program established the **California Climate Change Center** to document climate change research relevant to the states. This Center is a virtual organization with core research activities at Scripps Institution of Oceanography and the University of California, Berkeley, complemented by efforts at other research institutions. Priority research areas defined in PIER's five-year Climate Change Research Plan are: monitoring, analysis, and modeling of climate; analysis of options to reduce greenhouse gas emissions; assessment of physical impacts and of adaptation strategies; and analysis of the economic consequences of both climate change impacts and the efforts designed to reduce emissions.

The California Climate Change Center Report Series details ongoing Center-sponsored research. As interim project results, the information contained in these reports may change; authors should be contacted for the most recent project results. By providing ready access to this timely research, the Center seeks to inform the public and expand dissemination of climate change information; thereby leveraging collaborative efforts and increasing the benefits of this research to California's citizens, environment, and economy.

Assessment of Long-Term Electric Energy Efficiency Potential in California's Residential Sector is the final report for the Preliminary Economic Analyses of Climate Change Impacts and Adaptation, and GHG Mitigation project (contract number 500-02-004, work authorization MR-006) conducted by Itron, Inc.

For more information on the PIER Program, please visit the Energy Commission's website www.energy.ca.gov/pier/ or contract the Energy Commission at (916) 654-5164.

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Abstract

This study presents results from a long-term forecast of electricity consumption in California's residential sector to the year 2050. The model developed for this study's projections builds upon the California Energy Commission's (Energy Commission's) forecast results and historic input data for the period 1970 to 2015. These data are expanded upon using other sources, including long-term demographic forecasts, short-term bottom up energy-efficiency potential studies, econometric forecasts, and interviews with technologists on long-term emerging technology prospects. The focus of this work is on the interaction among key drivers of future electricity use, which includes population, energy efficiency, and end-use service demands. This study uses scenario analysis to address the major uncertainties associated with its long-term forecasting horizon.

This study's results show that although energy efficiency improvements may continue to provide significant reductions in electricity consumption through 2050, aggregate consumption also is likely to continue increasing, due to increasing population and energy service demands. Only under one extremely aggressive and optimistic scenario is residential electricity consumption reduced by 2050 to today's level; however, this scenario requires reducing per capita consumption by almost 40 percent, which would be an unprecedented accomplishment, given historic efficiency achievements, consumer's current adoption preferences, and continually increasing demands for energy services. Continuation of existing efficiency programs and standards, along with new, more much more aggressive policies, and a major change in consumer preferences would likely be necessary to achieve such reductions.

Keywords: Energy-efficiency potential, energy scenario analysis, long-term energy forecasting, residential energy use, residential energy use, and climate change

Executive Summary

Introduction

This study examined long-term electric energy efficiency potential for California's residential sector and developed a methodological and modeling framework that can be expanded to address the state's other building sectors and fuels. The target year for analysis was 2050.

Purpose

The purpose of this study was to explore the degree to which energy efficiency technologies and energy efficiency polices might contribute to reducing greenhouse gas emissions (GHG) over the long term.

Project Objectives

The research team's primary objective was to develop a method for forecasting long-term energy use and energy efficiency potential that could be expanded to address other building sectors and fuels. Specific project objectives included:

- Developing an approach that would take advantage of current information on energy efficiency technology characteristics as well as current and past end-use consumption patterns, without being tied to long-term and highly uncertain forecasts of individual technology costs, savings, and performance;
- Developing an approach that would take into account both changes in energy efficiency levels over time and changes in demand for energy services; and
- Developing an approach that would be flexible and easy to modify to accommodate alternative sets of assumptions affecting both efficiency potential and overall energy use.

Project Approach

The focus of this study was on the development of scenarios related to energy-efficiency potential. Other scenarios were developed to provide simple alternative forecasts of key exogenous drivers of total electricity consumption, such as population, housing density and aggressive residential photovoltaic (PV) market penetration. The population forecasts utilized were from the California Department of Finance (CADOF) and the Landis and Reilly study *How We Will Grow: Baseline Projections of California's Urban Footprint through 2100*. A modeling approach was developed that combined trend analysis, regression techniques, structured expert opinion, end-use and sub-sector segmentation, scenario development, and scenario simulation.

As part of this study, the research team developed three primary efficiency scenarios as described below.

- The Frozen Efficiency scenario provides a baseline scenario in which there are no further improvements in efficiency levels on the margin. Efficiency levels are generally

frozen at the marginal unit energy consumption (UEC) values for 2006 in the California Energy Commission's end-use forecast. Reductions in some average end use UECs still occur over time due to the natural turnover of technologies and housing stock.

- The Optimistic Efficient Technology (OET) scenario assumes significant penetration of energy-efficient technologies that will be at the edge of cost-effectiveness in 2050 but still can become widely adopted. California would need to pursue policies consistent with, or slightly more aggressive than, those presently in place. Attempts would be made to capture all cost-effective energy efficiency opportunities.
- The Green Dream scenario assumes the adoption of the most energy-efficient technologies expected to be available over the forecast period within existing technology paradigms. Technologies adopted in this scenario are not necessarily expected to be cost-effective. The Green Dream scenario purposefully pushes the envelope of what could be expected from efficiency improvements and associated policies absent significant technological and socioeconomic paradigm shifts. California would have to pursue polices that give preference to energy efficiency over other issues.

Project Outcomes

Key findings related to end-use efficiency improvements include the following:

- Significant improvements in efficiency have occurred for many end uses since 1970, particularly refrigeration, cooling, heating, and water heating. Some reductions in electricity consumption over this period were due to decreases in electricity end-use saturations. End-use service demand increased steadily for lighting, plug loads, and space conditioning (due to increasing home size).
- Much of the future savings potential identified is associated with improvements in lighting, refrigeration, and central air conditioning.
- End uses such as water heating, electric space heating, clothes drying and ventilation systems are likely to contribute less to overall reductions in consumption because they have either smaller relative savings potential, are end uses with low electric saturation, or have low baseline consumption.
- Communications and entertainment technologies will realize efficiency improvements but increased demand for these services will likely outpace the savings, resulting in a net increase in per-capita usage for those end uses.

Findings related to per capita consumption include the following:

- Per-capita electricity consumption increases slightly under the Frozen Efficiency due to increased home size and the use of communication and entertainment technologies, which offset efficiency improvements due to stock turnover.
- Per-capita residential electricity use could decrease by 9 percent and 33 percent from today's levels under the OET and Green Dream scenarios, respectively. The Green

Dream scenario would represent a dramatic increase in efficiency that goes well beyond California's historic rate of efficiency improvement.

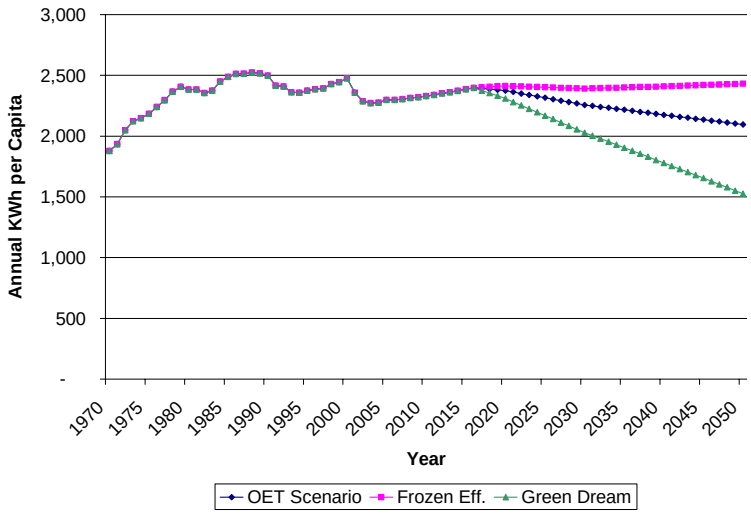

Figure ES-1: Resulting residential kWh per capita under efficiency scenarios

Findings related to total aggregate consumption are summarized below; unless indicated otherwise, these findings are all based on the CADOF population forecast:

- Population growth is the major driver in determining California's total residential electric energy consumption.
- In the Frozen Efficiency scenario, electricity use increases from roughly 83 terawatt-hours (TWh) today to approximately 133 TWh by 2050, a roughly 60 percent increase and similar to the forecasted growth in population. (Note that under the Landis and Reilly population forecast, electricity consumption increased to over 160 TWh by 2050—almost double current consumption.)
- Under the OET scenario, consumption is forecasted to increase to 116 TWh—roughly 16 percent less than under the Frozen Efficiency scenario, but still 40 percent more than today's level.
- Aggregate consumption under the Green Dream scenario would decline, after a rise from 2005 to 2016, to 84 TWh, or 37 percent less than under Frozen Efficiency.
- Only under an extremely aggressive scenario that combined a shift toward higher housing density (i.e., a shift away from single-family detached homes) with the Green Dream efficiency levels was electric energy consumption able to move below 1990 levels.
- An aggressive photovoltaic program, that would include 5 million solar powered houses, could save an additional 15,000 GWh per year by year 2050.

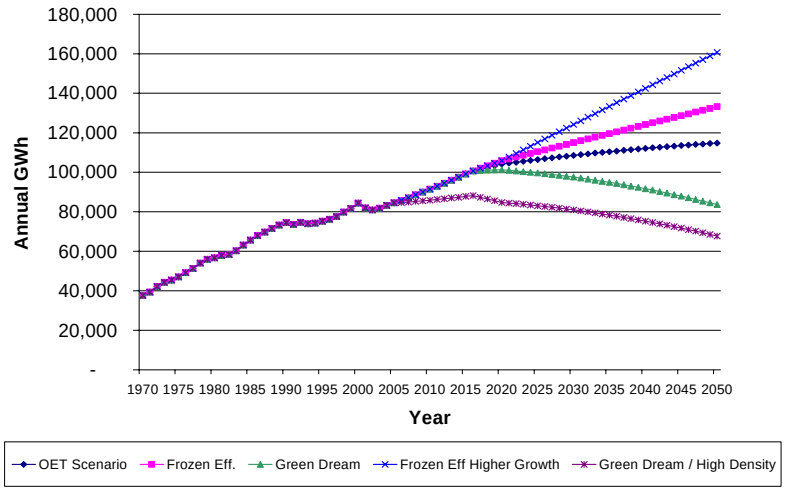

Figure ES-2: Total California residential electricity use under efficiency scenarios

Conclusions

This study's results show that although energy efficiency improvements may continue to provide significant reductions in electricity consumption through 2050, aggregate use also is likely to continue increasing, due to increasing population and energy service demand. Only under one extremely aggressive and optimistic scenario is residential electricity consumption reduced by 2050 to today's level; however, this scenario requires reducing per-capita consumption by almost 40 percent, which would be an unprecedented accomplishment, given historic efficiency achievements, consumers' current adoption preferences, and continually increasing demand for energy services. Continuation of existing efficiency programs and standards, rapid technological advancements, new more aggressive policies, and a major change in consumer preferences would likely be necessary to achieve such savings.

Recommendations

A number of further research activities should be considered. These include expanding the analysis to other sectors and other fuels (e.g., natural gas); enhancing the methodology in the current study by including fuel price forecasts, price effects, and technology cost forecasts; expanding the number and range of expert interviews used to support the service demand and efficiency scenarios; and continuing to support and expand the CEC's end-use forecasting and associated market studies.

Benefits to California

Energy efficiency is likely to play a key role in California's policies to reduce GHG emissions. To inform policies to reduce GHG emissions, it is important to improve understanding of the factors that drive aggregate energy use along with the potential impact of policies to improve efficiency and decrease consumption. The analysis used in this study provides a framework and initial set of results for long-term energy-efficiency potential analysis in the residential sector. This research will help to inform and improve analysis of greenhouse gas mitigation opportunities, challenges, and policies.

1.0 Introduction

1.1. Background

The study summarized in this report was designed to develop long-term estimates of electric energy efficiency potential for California's residential sector, as well as a methodological and modeling framework that can be expanded to address the state's other building sectors and fuels. This work was carried out for the California Energy Commission's (Energy Commission's) Public Interest Energy Research (PIER) program.[1] This study is part of a larger effort led by the University of California at Berkeley to develop economic analyses of climate change impacts and greenhouse gas (GHG) mitigation.

Conservation supply curves (CSCs) have been a primary tool of energy-efficiency analysis for the past quarter century. A key application of CSCs is the assessment of short-run (roughly, decade-long) potentials for deployment of energy-efficient technology. Several large-scale studies of this type have been conducted for California.

These CSCs have certain shortcomings, however, that have limited their range of applicability. First, they are intrinsically static; while this serves the purpose of short-run analysis, it is a key impediment to longer-run assessments of efficiency potential, where the effects of technological change become increasingly important. This limitation is particularly important in the context of carbon dioxide or GHG abatement analysis, in which longer-term phenomena are the critical focus.

Second, there has been inadequate effort to develop the economic underpinnings of CSCs, which therefore remain primarily an engineering methodology.[2] This is a very important factor in the near-complete exclusion of energy-efficiency analysis both potentials and policy analysis from the economic simulation models, which in turn has resulted in an almost complete absence of energy efficiency from economic simulations related to carbon abatement policies.

The established methodology for developing supply curves for energy efficiency focuses on the short term; in current and previous studies for California, the time horizon is or has typically been a single decade. Such relatively short forecast periods reflect the requirement of detailed data on both the cost and performance characteristics of the technologies and measures to be included and on underlying input variables such as housing stock characteristics and spatially disaggregate baseline energy consumption trends. These data pertain not merely to specific technologies but in many cases to individual devices. Overall,

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[1] This work was carried out under the Global Climate Change element of PIER's Energy-Related Environmental Research Area.

[2] See Rufo 2003 for a discussion of the limitations of traditional CSC approaches. Note also, however, that there are a number of energy-efficiency potential studies that apply calibrated adoption modeling techniques to forecast energy-efficiency potential (KEMA-XENERGY 2003; Itron 2006) based on observed customer behavior, as well several studies that focus on analysis of barriers to energy efficiency in attempts to explain the gap between CSC-implied cost effectiveness and actual customer adoption (Eto et al. 1997; Sathaye and Murtishaw 2004).

a conventional supply curve represents an incremental perturbation to observable energy technology and demand trends given *known* technologies for increasing efficiency levels.

In the longer run, however up to multiple decades a different approach is needed to extend the supply curve methodology. First and foremost, over these time scales the technology "menu," or set of possibilities for increased efficiency, cannot be known with certainty and indeed will itself depend on policies, long-run market trends, and other drivers that do not enter directly into the standard supply curve method. Thus, estimating long-run supply curves requires developing a potential-estimation approach that incorporates methods for economic, demographic, and technology projections. Second, these conditions imply that long-run supply curves cannot be built with the same level of technology detail as short-run curves: there are no methods for plausibly projecting the costs and characteristics of specific devices multiple decades into the future at the level of detail contained in standard supply curves. For these reasons, a longer-run approach cannot be simply an extrapolation of the current supply curve method. Thus, a new methodology must be developed, and appropriate variations specified as necessary for the different sectors that will be analyzed.

1.2. Scope and Objectives

The challenge of this study is to develop a new, initial, methodology that combines the lessons learned from thermodynamic, engineering, and economic analysis. This needs to be a dynamic methodology to allow for the impact of alternate policy and energy futures. This study was intended as the first in a set of efforts to develop long-term forecasts of electric and natural gas energy efficiency potential in California's buildings sectors. The scope of this study includes only California's residential electricity sector. Other sectors and fuels will be addressed in future PIER research. The current study was designed as an initial effort to develop a methodology for long-term forecasting of building energy use that maintains important sub-sector consumption details (principally, end-use consumption) while purposefully avoiding technology-specific modeling. This study was designed to easily enable simulation of alternative futures based on changes in exogenous (e.g., population forecasts) and endogenous (e.g., end-use efficiency levels) factors.

Key questions addressed by this study include the following:

- What methods would be most appropriate for long-term (50 to 100 year) forecasting of residential electricity consumption?
- What factors explain historic trends in residential electricity use in California?
- What are the major drivers that will contribute to long-term residential electric energy consumption in California?
- What are realistic ranges of expectations for the role of electric energy efficiency improvements in reducing long-term residential electricity consumption in California through the year 2050?
- What are the key factors and policy implications associated with alternate energy efficiency potential scenarios?

1.3. Guide to this Report

The remainder of this report is organized as follows:

- Section 2 – Methodology and Modeling Considerations explores a variety of traditional modeling approaches that were considered for this analysis and presents a discussion of the approach employed.
- Section 3 – Key Data Sources and Adjustments discusses the data sources used in the analysis. The section also presents the rational and methodology used to consolidate and disaggregate data for the analysis.
- Section 4 – Development of Scenarios describes the scenario components used in the analysis and how they were combined and applied to capture the range of outcomes.
- Section 5 – Retrospective End-Use Review, Development of Future UEC and Saturation Scenarios presents a discussion of each residential electric end use and how it is expected to change by 2050 under both the OET and Green Dream scenarios, given this study's estimates of changes in utilization and efficiency.
- Section 6 – Summary of Observations from Retrospective Analysis provides a distillation of the historic trends and key drivers of residential electricity consumption that were observed as part of the research.
- Section 7 – Scenario Analysis Results present this study's model results for each of the key scenarios developed.
- Section 8 – Recommendations for Future Research provides suggestions for related future research.
- Section 9 – Sources lists the sources reviewed for this study.

2.0 Methodology and Modeling Considerations

Prediction is very difficult, especially about the future.
Niels Bohr

There is no foolproof methodology for looking far into the future. In preparation for this study, the research team considered a variety of approaches, ranging from top-down econometric to fully bottom-up, technology adoption models. Ultimately, the team rejected deterministic approaches and developed instead a hybrid approach that relies on a combination of trend analysis (of both consumption as well as technology characteristics and holdings), regression techniques, structured expert opinion, end-use and sub-sector segmentation, scenario development, and scenario simulation. This approach adapts well to the challenges presented by the limited availability of electric decomposition data, associated inconsistencies among the data that do exist, and immutable uncertainties about the future (e.g., that past trends, though critical and informative to long-term forecasting, cannot, in the end, provide a reliable roadmap for the future).

Study tasks included analyzing the major factors contributing to changes in California's residential electric energy consumptions from 1970 to the present, modeling the relationship among these factors and overall consumption, forecasting endpoints for each contributing factor and, lastly, estimating total usage under a set of alternative futures. At each stage of data development and for each component of the analysis, the validity of historic and exogenous forecast data was assessed, short-term models were calibrated to available known values, and results examined in the context of long-term trends to ensure plausibility.

2.1. Approaches Considered

This section discusses the different modeling approaches considered for this study. As discussed further below, the research team chose to use an end-use level scenario analysis instead of an elasticity-based approach or technology adoption model.

2.1.1. Elasticity-Based Approaches

Price elasticities derived from econometric analyses of aggregate residential energy use have been utilized in many retrospective studies and short-term forecasting applications. These approaches generally use cross-sectional and longitudinal data of energy consumption, energy prices, income, economic conditions, and weather. The results are usually expressed in terms of short-term and long-term elasticities, as well as whether they are own-price or cross-price elasticities. The results of these analyses are commonly used for short-term forecasting (e.g., 5 to 10 year horizons) and can be accurate and effective in such applications. However, for the purposes of this study, there are major limitations associated with these econometric approaches and associated elasticity results.

Traditionally, elasticities are derived statistically and are based on correlations between changes in prices and changes in consumption. They are almost always calculated at the whole-house level, not at the end-use level. Though most price elasticities capture the percent change in energy consumption relative to a percent change in energy price, they do not provide precise information about how consumption was changed, for example,

whether it was through changes in use of particular end-use technologies, changes in end-use energy services, fuel switching, or changes in end-use efficiency levels.

Furthermore, like any statistically derived value, elasticities provide useful information within the constraints of the data and time period analyzed but are of much more limited value when applied to future conditions if there is strong reason to believe that those conditions may be significantly different than the historic circumstances in which they were estimated (i.e., they are useful as in-sample results but are more limited when applied to out-of-sample conditions). This is particularly important when there are underlying structural changes in the historic period that are unlikely to continue or will change dramatically in the future.

Estimated household electric price elasticities have tended to range widely from -0.08 to -1.02 (Reiss and White 2004) for the short term and typically much greater for the long term. A key problem associated with existing long-term estimates is that results can be strongly affected by end-use characteristics, fuel substitution effects, and relatively narrow ranges of price differences. In addition, fuel substitution can be a strong factor in long-term studies; however, there are only a few end uses for which fuel substitution is viable: typically, heating, water heating, and cooking. For example, in regions where electricity prices and have increased over time while natural gas infrastructures have expanded, major shifts have historically occurred from electric to natural gas heating. In some regions, like California, this shift has clearly reached a limit in that the remaining saturation of electric heating and water heating is now very low. Thus, the remaining potential for savings associated with fuel switching is much lower for the future than it was in the past. It is also likely that elasticities are very end use sensitive. For example, although consumers' have moderately reduced service levels in response to higher prices for end uses such as space heating and lighting, there is little evidence of any effect on the discretionary use of other key end uses such as refrigerators and televisions.

Ultimately, though, the key problem with price elasticity estimates to date is that they lack resolution at the end-use level and can produce physically implausible results when used for long-term forecasting or scenario analysis. This study requires an approach that is structurally based and provides transparent analysis of the wide variation in service demands and efficiency potentials that occur across individual residential end uses.

2.1.2. Technology and End-Use Level Approaches

Instead of using price elasticities directly, the approaches used in this study are drawn from retrospective energy decomposition methods (see, for example, Schipper et al. 2001), traditional conservation supply curve (CSC) methods (Meier et al. 1982), prospective technology adoption models (Rufo 2003; Rufo and Coito 2002; Rogers 2003), and scenario analysis. However, in a departure from fully bottom-up technology adoption approaches (which model adoption decisions about individual technologies and practices), the model developed for this study operates at the end-use level. The rationale for this approach is discussed below.

Technology-rich, bottom-up analyses typically assume a prototypical base case technology and apply prototypical efficient technologies to these base case technologies, thereby simulating alternative decisions faced by end users. However, the base and energy-efficient

technology characteristics in these studies are usually static. The results of these analyses often provide a snapshot of technical and economic potential at a given point in time. In some studies, customer adoption is also explicitly modeled. In practice, this method can be very powerful for forecasting adoption in the very short-term (under five years) and is reasonable for forecasting within a 10-year period. However, the validity and accuracy of this approach diminishes quickly with the length of the forecasting horizon since, by definition, decision making and usage are tied to a discrete set of detailed technology-specific characteristics that can only be known well in advance of the forecast year of interest. For example, numerous studies have incorrectly predicted the "next" major energy efficiency technology.

At the same time, energy researchers and technologists have a strong understanding of the engineering and economic characteristics of technologies that are available to end users today, as well as of some of the technologies that are likely to be available in the next five to ten years. However, it is also clear that energy researchers and technologists have a limited ability to predict specific technologies and associated characteristics further out into the future (i.e., more than ten years). Note, however, that this is not the same as saying that researchers are equally limited at higher-level forecasting of efficiency gains over the longer term. Past studies of sectoral consumption and efficiency potential have been able, in some cases, to capture longer-term decreases in total consumption at an aggregate level. In addition, numerous efficiency improvements that were not predicted have occurred over the past 25 years.

Of course, if trends are forecasted at too aggregate a level, important information can be lost on physical or other intuitively compelling characteristics that directly affect long-term opportunities and constraints. As discussed below, rather than forecast to 2050 at a level that the research team believes is too deterministic and difficult to defend (i.e., the technology level), or one that is too divorced from physical and lifestyle factors (i.e., aggregate household usage), the team decided to conduct the analysis for this study at an end-use level in which consumption is modeled as a function of demand for energy services and the efficiency of the energy service delivered.

2.2. Modeling Approach Used for this Study

This section presents this study's basic modeling approach. The analysis is performed at the level of end-use energy services. Changes in end-use services over time are modeled as a function of two factors: changes in the efficiency of the end use, and changes in the demand for the end-use service. Total consumption is, of course, a function of average end-use consumption and the number of households that have each end use. This end-use modeling approach is described further below.

2.2.1. Summary of Basic Modeling Equation

Estimates of unit energy consumption (UEC) expressed in kilowatthours (kWh)/household embed both the demand for energy services and efficiencies of the technologies necessary to deliver the services. To the greatest extent possible assumptions about change in usage versus change in efficiency are made explicit in this study's modeling approach. Given the limitations of detailed technology-level modeling discussed above, the research team developed a relatively simple modeling equation and method for this study that is

structured at the end-use level. The primary equation used to forecast electricity consumption is defined as follows:

Total Annual California Residential Electric Consumption $= REC_y = \Sigma E_{esy,}$

where:

E_{esy} = Annual End Use Consumption = $UEC_{esy} * SAT_{esy} * HH_{sy}$

E_{esy} = total energy consumption for end-use (e) in market segment (s) in year (y)

UEC_{esy} = unit energy consumption for end-use (e) in market segment (s) in year (y)

SAT_{ys} = saturation for end-use (e) in market segment (s) in year (y)

HH_{ys} = number of households in market segment (s) in year (y)

Unit energy consumption is further disaggregated into the following relationship:

$UEC_{esy} = UEC_{es2006} * EffAdj_{esy} * UseAdj_{esy}$

where:

UEC_{es2006} = unit energy consumption for end-use (e) in market segment (s) in year 2006

$EffAdj_{esy}$ = efficiency adjustment = relative efficiency level in year (y)/relative efficiency level in 2006 (defined as 1.0)

$UseAdj_{esy}$ = usage adjustment = relative energy service demand in year (y)/relative energy service demand in 2006 (defined as 1.0)

The approach the research team developed is similar to an approach used for a recent long-term energy analysis conducted by Pacific Northwest National Laboratory (PNNL) (Rong et al. 2006).

The research team's analysis uses data from the Energy Commission's end-use forecasting model for the period 1970 through 2004 (CEC 2005b through 2005i). It also uses the Energy Commission's forecasts for the period 2005 through 2016.[3] The team then developed endpoint values for each of the key factors in the equation above for the year 2050. Different endpoint values were developed for different scenarios as discussed further below. These endpoint values were developed through interviews with technology experts, a literature review, and the research team members' best judgment. The model then uses linear interpolation to calculate the factors from 2017 through 2049. The endpoint values and equations also take into consideration changes in efficiency and service levels associated with stock turnover. These underlying end-use service and efficiency factors are discussed in Sections 4 and 5.

[3] For one Energy Commission end use—Miscellaneous —the research team decomposed lighting from all other miscellaneous loads. This decomposition is described in Section 3.

2.2.2. Forecasting Technology Change within Existing Paradigms

Technology change can occur over time in many ways. However, it is useful to consider two broad classes of technology change. The first is through a continuation and improvement of the characteristics of an existing, known technology. Most efficiency improvements over the past 25 years fall in this category (e.g., improvements in air conditioner seasonal energy efficiency ratio (SEER) levels). The second type requires a shift from a known technology to an entirely new technology (e.g., if light-emitting diode (LED) lighting were to replace fluorescent and incandescent lighting in mainstream applications). This second type of technology change can be thought of as a paradigm shift and is, by definition, extremely difficult if not impossible to predict. While technology experts can make fairly good predictions about efficiency potentials within known technologies using engineering principles, it is nearly impossible to accurately predict technology paradigm shifts and their effects on energy use. It is impossible to know if one will occur, when one will occur, or what impact it may have should it occur. For this reason, the efficiency potentials and associated scenarios used in this study are primarily limited to existing technology paradigms. It is certainly possible to take the methods and models developed for this study and develop additional scenarios that are based upon assumptions about efficiency and service demand changes that might be associated with paradigm shifts.

2.2.3. Technology Change over Time

For the purpose of this analysis, the research team assumed that all electricity consuming technology will be replaced at least once, and most likely several times, between the present and 2050. Although a full stock accounting methodology could have been utilized in this study, it was beyond the scope planned for this initial effort. However, for most end uses, as noted previously, the team instead forecast an average UEC in the target year of 2050, which eliminates the need for explicit stock accounting, since most technologies will turn over one or more times over the forecast period. Central air conditioning and electric space heating are two exceptions for which additional adjustments were made. Building shells, which exert significant influence over energy consumption related to cooling and heating, tend to remain constant for long periods and are as significant in the assessment of space conditioning consumption as the efficiency level of the cooling and heating delivery technologies.

For most end-uses, the research team forecasts average UECs for the year 2050 by starting with the marginal UECs for the year 2006. The team then assesses how future technology will be improved over today's technology today. The same process was used to forecast efficiency improvements in heating and cooling technology for electric space heating and central air conditioning but the interaction between the technology and buildings constructed at varying times was also considered. To account for these differences in building stock, the research team used a minimal stock accounting algorithm that segments all current housing from all future housing. For the existing housing stock, the research team applied technology improvements to the entire stock. Shell improvements resulting from new codes and standards were also applied to the portion of this existing stock that will realize these improvements through renovation and replacement. The 2006 average UEC in each climate zone was used as the starting point for the existing housing assessment. For new housing stock, the 2006 marginal UEC in each climate zone was used and the

research team applied the same technology improvements along with shell improvements to all housing stock resulting from new codes and standards.

2.2.4. Fuel Switching

Direct modeling of fuel switching was not within the scope of this study. It is thus implicitly assumed that most households in California capable of switching away from electricity to natural gas for the purposes of heating, water heating, and cooking have made those changes or will have made those changes within the Energy Commission's forecast to 2016. As discussed in Section 3 of this report, there was a significant decrease in electric saturation for these end uses prior to 1990. The rate of fuel switching since then has been much slower. Many of the households that currently use electricity for these heating end-uses do not have a practical or cost-effective alternative (e.g., because they lack access to natural gas service). It is of course possible that fuel-switching rates could increase in the future under alternative futures if the factors leading to the current equilibrium among key fuels (e.g., relative fuel and technology costs) were to significantly change. Fuel switching will be explicitly addressed in a future phase of this work.

2.2.5. Market Segmentation

The market segmentation used for this study generally followed the approach utilized in the Energy Commission's end-use forecasting models, with a few exceptions. The research team segmented the market into single-family and multifamily households. Mobile homes, which are included as a segment in the Energy Commission's model, were aggregated into the single-family segment for this analysis. For climate sensitive end uses, homes were further segmented into the Energy Commission's 16 *forecasting*[4] climate zones.

Table 2-1 summarizes the market segmentation used. It should be noted that hot tub pumps and hot tub heating are not included as market segments for multifamily dwellings because there are negligible saturations of these technologies in multifamily homes. As will be discussed below, the single-family and multifamily segments for climate sensitive end-uses in Climate Zone 1 use the same average UEC and end-use saturations.

Finally, the Energy Commission has no end-use data for Climate Zones 14 and 15. Both of these climate zones are sparsely populated and have relatively low energy consumption levels. The research team generally assumed that Climate Zone 15 (Imperial County) is similar to Climate Zone 10 which includes the vast majority of inland and desert portions of Southern California, from San Bernardino east. Climate Zone 14, which is mountainous in northern and eastern California, most resembles Climate Zone 1. A total of 138 end-use market segments were analyzed.

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[4] Note the reference here is to the Energy Commission's *forecasting* climate zones. The Energy Commission also utilizes 16 climate zones to define zones for its Title 24 building standards. The Energy Commission's forecasting zones and Title 24 zones are not the same.

Table 2-1: Summary of study market segmentation

CEC End-Use Number	Non-Climate-Dependent End Uses	Single Family	Multifamily
1	Water Heating	Yes	Yes
4	Dishwasher	Yes	Yes
5	Water Heating - Dishwasher	Yes	Yes
6	Clothes Washer	Yes	Yes
7	Water Heating - Clothes Washer	Yes	Yes
8	Clothes Dryer	Yes	Yes
9	Miscellaneous	Yes	Yes
10	Cooking	Yes	Yes
11	Refrigerator	Yes	Yes
12	Freezer	Yes	Yes
15	Swimming Pool Pump	Yes	Yes
18	Hot Tub Pump	Yes	No
19	Hot Tub Heating	Yes	No
25[5]	Lighting	Yes	Yes
CEC End-Use Number	**Climate-Dependent End Uses**		
20	Electric Space Heating		
21	Furnace Fan - Gas Space Heating		
22	Central Air Conditioning		
23	Room Air Conditioning		
CEC End-Use Number	**Climate Zone Code**	**Single Family**	**Multifamily**
20, 21, 22, 23	CZ1	Yes	Yes
20, 21, 22, 23	CZ2	Yes	Yes
20, 21, 22, 23	CZ3	Yes	Yes
20, 21, 22, 23	CZ4	Yes	Yes
20, 21, 22, 23	CZ5	Yes	Yes
20, 21, 22, 23	CZ6	Yes	Yes
20, 21, 22, 23	CZ7	Yes	Yes
20, 21, 22, 23	CZ8	Yes	Yes
20, 21, 22, 23	CZ9	Yes	Yes
20, 21, 22, 23	CZ10	Yes	Yes
20, 21, 22, 23	CZ11	Yes	Yes
20, 21, 22, 23	CZ12	Yes	Yes
20, 21, 22, 23	CZ13	Yes	Yes
20, 21, 22, 23	CZ16	Yes	Yes

[5] In this study lighting is a distinct end use and has been assigned the Energy Commission End-Use Number 25, which is not an actual Energy Commission End-Use Number.

2.2.6. Climate-Dependent End-Uses

This study only treats heating and cooling as climate-dependent end uses. Although other end-uses are also influenced by climate (e.g., water heating), the effects are mostly small and the data available do not support a greater degree of segmentation.

Four primary factors are estimated to impact residential energy use intensity for heating and cooling in the year 2050. Location is the first. Housing located in hot inland regions tends to use more air conditioning than that in cooler coastal regions. Building efficiency is the second factor. Buildings with more insulation and less infiltration maintain the temperature differential between inside and outside air more efficiently and consequently require less heating and cooling. The third factor is technology efficiency. High efficiency space conditioning systems provide the same amount of heating and cooling using less energy than less efficient systems. The fourth factor is the heating and cooling, which is primarily a function of indoor temperatures and related usage behavior and home size.

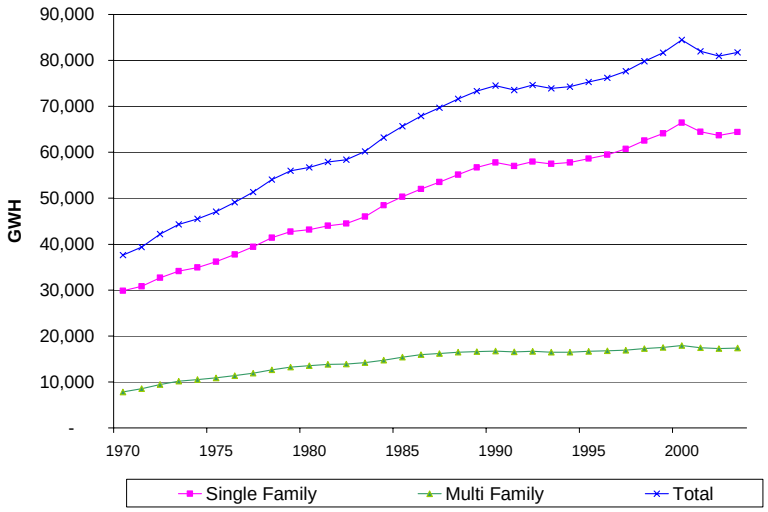
As discussed further in the following section, this study utilized population forecasts that project growth by climate zone. The major trend is toward more growth in the warmer inland portions of California. This holds true for both northern and southern California, leading to similar forecasts for changes in heating and cooling end uses in both regions.

3.0 Key Data Sources and Adjustments

Any analysis is only as good as the data used in it and there is rarely a perfect set of data. After a thorough review of all available data sources, the research team determined that the Energy Commission's end-use forecasting data was the best available for the purpose of this study. These are the most comprehensive, complete, and consistent California-specific data available. Although there have been changes in input sources and collection methods over time, and changes in forecasting unit calculation methods, all told, these data present a reasonable picture of residential energy consumption at the end-use level from 1970 to the present. These data have been reconciled to actual electric energy consumption on a periodic basis and have been used by the state of California in its planning and forecasting processes for over twenty years. Furthermore, the Energy Commission data has been scrutinized and vetted to a greater degree than any other known data set that considered for this study.

3.1. Energy Commission End-Use Data

The data used in this analysis were provided by the Energy Commission in September 2005 (CEC 2005b through 2005i). The Energy Commission's most recent forecast of residential electricity consumption, along with historic consumption is shown in Figure 3-1. A breakdown of the Energy Commission's estimated consumption for 2004 by end use is provided in Table 3-1. The last year for which the forecast data were reconciled by the Energy Commission to actual load data was 2004. All data presented for the years between 1970 and 2004 are historic data from the Energy Commission's model. Data presented for the years 2005 through 2016 are primarily Energy Commission forecast results, with a few exceptions that are identified. Data presented later in this report for the years 2017 through 2050 are forecasts by the authors.



Source: CEC 2005b through i

Figure 3-1: Total residential electricity consumption, 1970 to 2004

Table 3-1: Breakdown of California 2004 residential electricity consumption by end use

End Use	TWh	Percent (%)
Water Heating	2.6	3
Dishwasher	2.3	3
Water Heating - Dishwasher	0.8	1
Clothes Washer	0.8	1
Water Heating - Clothes Washer	1.2	1
Clothes Dryer	6.6	8
Other	16.3	20
Cooking	4.1	5
Refrigerator	14.3	17
Freezer	3.3	4
Swimming Pool Pump	3.4	4
Hot Tub Pump	1.1	1
Hot Tub Heating	0.2	0
Lighting	16.5	20
Space Heat	3.3	4
Fan for Gas Furnace	1.4	2
Central Air Conditioning	4.7	6
Room Air Conditioning	0.5	1
Total	83.3	100

3.2. Population and Housing Considerations

Energy consumption calculations at the end-use level are based on the number of households having each end-use. Although Energy Commission data contain household estimates for the years 1970 through 2016, there are no readily available estimates of the number of households by housing segment out to the year 2050. The best proxy data available are total population forecasts. Housing estimates used for this analysis are extrapolated from population estimates, as described below.

3.2.1. Population Forecasts

This analysis considered two sources of projected population estimates for the year 2050. The first source is a report by the California Department of Finance (CADOF), which provides county level population forecasts by decade through 2050 (CADOF 2006). The second is a study of baseline projections for California's urban footprint through 2100 (Landis and Reilly 2003). The latter provides forecasts of population for the years 2000, 2020, 2050, and 2100 for each county. The two studies project different total population estimates for California in the year 2050, as well as different regional population distribution patterns.

California's population grew at an average annual rate of 1.7 percent from 1970 to 2000. Landis and Reilly (2003) projects an average annual rate of 1.3 percent between the years 2000 and 2050, while the CADOF forecast is slightly lower, at 1 percent per year. These forecasts are shown and discussed further below.

3.2.2. Household Types

The Energy Commission data contains four household type definitions: single-family, multifamily, mobile home, and combined. The combined category is only used for climate-sensitive loads in one climate zone.

Over the last 25 years, there has been a slight increase in the relative share of single-family households and a slight decrease in the relative share of mobile homes, as shown in Table 3-2.

Table 3-2: Relative share of dwelling type in California

	1980 (%)	1990 (%)	2000 (%)	2005 (%)
Single-family	61.7	61.1	62.5	63.0
Multi-family	30.9	31.2	30.7	30.5
Mobile Home	7.4	7.7	6.8	6.5

Similarly, as shown in Table 3-3, the relative proportion of energy consumed by each dwelling type shows an increase in the relative share of single-family energy consumption and a decrease in the relative share of mobile home energy consumption.

Table 3-3: Relative energy consumption by dwelling type in California

	1980 (%)	1990 (%)	2000 (%)	2005 (%)
Single-family	71.2	73.1	75.1	75.5
Multi-family	23.4	22.0	20.8	20.5
Mobile Home	4.6	4.5	3.8	3.6
Combined	0.8	0.5	0.4	0.4

Based on analysis of UECs, it is clear that while mobile homes typically use energy at a rate between that of single-family households and multifamily households, for most end-uses, mobile home consumption more closely resembles that of a small single-family dwelling than a multifamily one. Mobile homes are aggregated with single-family households in this analysis due to these similarities and because of the relatively small proportion of housing stock they form and even smaller contribution they make to total electric energy consumption. In Climate Zone 1 there is no distinction between housing types for climate-sensitive loads. The Energy Commission data only present a combined housing type. For simplicity the research team applied the same average UEC and end-use saturates to both single-family and multifamily households.

3.2.3. Counting and Locating Households

In large part, household location drives energy consumption required for cooling and heating. Mapping each county's forecast population to the appropriate climate zone was therefore an initial study task. The Energy Commission includes a mapping of county to climate zones in the documentation of its end-use forecasting model. Climate Zone 15 population estimates were included with Climate Zone 10 estimates and Climate Zone 14 estimates were included with Climate Zone 1 estimates.

For those counties containing more than one climate zone, the population was divided between the zones. For those counties where the data show a consistent proportional segmentation of population between multiple climate zones over time, that proportional distribution was maintained in assigning forecast population in 2050 to climate zones. However, when the data revealed a trend within a county of population shifting from one climate zone to another, the research team extrapolated the trend to forecast the population split in 2050.

The population growth rate in each climate zone was calculated by comparing population increases from the year 2000 to the forecast population in year 2050. The percentage change in population in each climate zone was applied to single- and multifamily households in the same climate zone. Applying the percent change in population in each climate zone to the single- and multifamily households in the year 2000 produced forecasts for single- and multifamily households for the years 2020 and 2050. Using the Energy Commission household estimates in 2005 as one point and the 2020 forecast of households as another point, all subsequent years were estimated using linear extrapolation. The linear extrapolation was repeated to fill in household estimates between the years 2020 and 2050. This method preserved variation among climate zones in both the number of people per household and the split between single- and multifamily households, as shown in Table 3-4.

3.2.4. Household Size

The size of both single- and multifamily homes has been increasing over time. All other factors being the same, an increase in home size necessarily increases the energy requirements for space heating, cooling, and lighting. Increases in home size also likely increase the general consumption of a variety of other energy-consuming products causing an increase in miscellaneous energy consumptions as well.

According to the U.S. census data (NAHB 2005; Wilson and Boehland 2005),[6] the size of the average new single-family home has increased by about 25 square feet per year since 1950. New single-family homes have increased from about 1,000 square feet in 1950, to 1,500 square feet in 1970, to 2,330 square feet in 2003—and the increase in size appears to be continuing. Multi-family units have also increased, although not nearly as fast. Census data (U.S. Census Bureau 2006a) for the western United States indicates that new multifamily homes have increased an average of five square feet per year from 1978 through 2004. Existing homes have also been getting larger through renovations that include additions.

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[6] The National Association of Home Builders (NAHB) used historic U.S. Census data in their summary of home size over time.

Table 3-4: Population growth rate forecasts by climate zone

Climate Zone	Population Base (Millions) Year 2000	Application of Landis Forecast: Population Forecast (Millions) Year 2050	Application of Landis Forecast: Forecast Growth (%)	Application of CADOF Forecast: Population Forecast (Millions) Year 2050	Application of CADOF Forecast: Forecast Growth (%)
1	0.79	1.54	195	1.16	146
2	1.02	2.44	239	2.82	276
3	2.81	6.98	249	5.99	214
4	4.90	8.98	183	7.84	160
5	3.10	4.4	142	3.91	126
6	1.23	2.41	196	2.86	232
7	0.56	1.51	271	1.30	233
8	6.58	10.47	159	8.32	127
9	2.91	5.59	192	3.48	119
10	3.42	10.93	320	7.93	232
11	2.17	3.01	139	2.59	119
12	1.31	2.15	164	1.57	119
13	2.83	5.83	206	4.51	159
16	0.42	0.66	157	0.50	119
Total California	**34.04**	**66.90**	**197**	**54.78**	**161**

It is difficult to say whether the general linear growth trend will continue or if home sizes will stabilize or possibly decline. For this study the research team assumed that growth will continue at an average rate of 19 square foot per year for single-family homes through the end of the decade and then drop to an average growth rate of 5 square feet per year from 2010 through 2050. The team estimated that new single-family homes will be 15 percent larger by 2050 than they are today. New multifamily homes are forecast to increase in size by an average of two square foot per year through 2050, or about 40 percent of the historic growth rate. These estimates of increasing home size are used to inform the team's estimates of increased service demand for space conditioning and lighting, which are discussed in Sections 4 and 5.

3.2.5. Climate Zone Variation in Housing Mix and Persons per Household

As discussed above, the method used to convert population to households preserves both the single-family/multifamily mix plus a static number of persons per household.

When considering California as a whole, the relative proportion of single-family to multifamily households has been fairly consistent over the past 35 years. Single-family households constitute almost 70 percent of the market, while multifamily households make up a little over 30 percent. Over the same time period the number of people per household has varied from about 2.75 per household to almost 3.1. Table 3-5 shows the historic state trends.

Table 3-5: Market segment share and persons per household by year in California

Year	Segment Share		Persons per Household
	Single Family (%)	Multifamily (%)	
1970	69.2	30.8	3.05
1975	67.9	32.1	2.88
1980	68.3	31.7	2.76
1985	67.8	32.2	2.85
1990	68.0	32.0	2.89
1995	68.3	31.7	2.95
2000	68.6	31.4	3.04
2005	68.8	31.2	3.07

Source: **(CEC 2005b through i; CADOF 2006)**

However, when examining the housing mix and occupancy patterns across climate zones there is much more variation, as shown in Table 3-6. The housing mix is particularly important in the analysis of climate-dependent end uses. As summarized in Section 4, the research team developed two housing density scenarios (here density is referred to in terms of the relative mix of single-family versus multifamily homes). In the first baseline housing density scenario, the research team assumed that all new growth will follow the existing housing mix pattern in each climate zone. In the second, high-density, housing scenario, the ratio of multifamily to single-family homes was increased as described in Section 4.

The persons-per-household ratio also affects end-use energy consumption, but its impacts tend to be relatively small and most pronounced for non-climate-dependent end uses like clothes washers. Testing the effect of changing the overall people-per-household ratio indicated that impacts were relatively insignificant especially in light of the uncertainty inherent in such a long-range forecast.

3.3. Consolidation of End Uses

The research team consolidated several end uses with the Energy Commission's "Miscellaneous" end use and created a consolidated "Other plus Lighting" end use. At the same time, as discussed below, the team developed its own estimated of the lighting end use, which was included but undifferentiated in the Energy Commission's "Miscellaneous" end use, and removed to produce two new end uses: "Other" and "Lighting."

Table 3-6: Market segment share and persons per household by climate zone in California

Climate Zone	Segment Share		Persons per Household
	Single Family (%)	Multifamily (%)	
1	89.2	10.8	3.30
2	79.7	20.3	2.99
3	80.5	19.5	3.13
4	74.3	25.7	3.20
5	59.8	40.2	2.43
6	74.3	25.7	2.66
7	84.0	16.0	3.37
8	68.8	31.2	3.01
9	67.3	32.7	4.70
10	81.9	18.1	3.45
11	39.0	61.0	2.28
12	57.8	42.2	3.05
13	66.2	33.8	2.72
16	49.0	51.0	2.53

Source: **(CEC 2005b through i; CADOF 2006)**

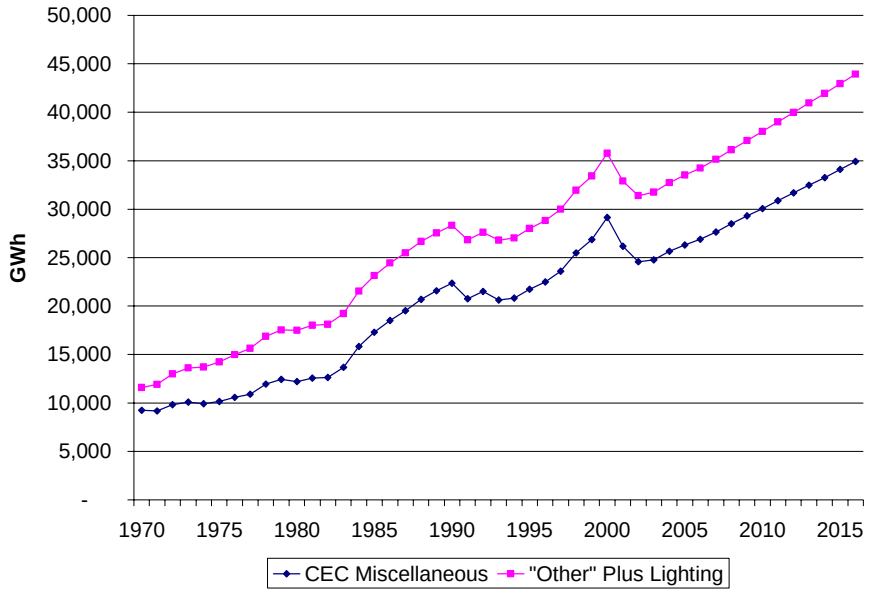
First, end uses with very low electric saturation, minimal energy consumption, less reliable UECs, and few policy alternatives to control unit energy consumption were consolidated with the Energy Commission's "Miscellaneous" category into the "Other plus Lighting." These end uses include the following Energy Commission end uses: electricity for solar water heating, electricity for solar water heating system pumps, electricity for swimming pool heating, electricity for swimming pool solar heating backup, waterbeds, and evaporative coolers. Most of these end-uses have a negligible impact on total state electricity consumption.[7]

The color television end use was also moved into the Other end-use category. Color TVs have nearly 100 percent saturation in all planning areas and have essentially the same energy consumption trend characteristics as other miscellaneous items. The number of TVs is increasing on a per-household basis (KEMA-XENERGY et al. 2004). Although there are factors that are increasing the energy efficiency of TVs, these increases are driven by factors other than energy economics. Furthermore, the increases in TV operating efficiency are offset by increases in size and other service demands (Calwell 2005a). Finally, as with other

[7] The exception was the waterbed category, which, according to the Energy Commission, does not document waterbed energy consumption alone, but was also used in the past as a second repository for miscellaneous end uses as part of model reconciliation.

miscellaneous items, TV technology and utilization dynamics are so fluid that policy alternatives to control unit energy consumption are limited.

When the end-uses are consolidated, the newly defined "Other plus Lighting" category included 29 percent more energy than the Energy Commission's "Miscellaneous" end use, as shown in Figure 3-2.



*The "Other" end-use category includes electricity for solar water heating, electricity for solar water heating system pumps, electricity for swimming pool heating, electricity for swimming pool solar heating backup, waterbeds, evaporative coolers, and the Energy Commission's "Miscellaneous" end use, including lighting.

Figure 3-2: Total consumption for the Energy Commission's "miscellaneous" end use and consolidated "other plus lighting"*

3.4. Disaggregating Lighting

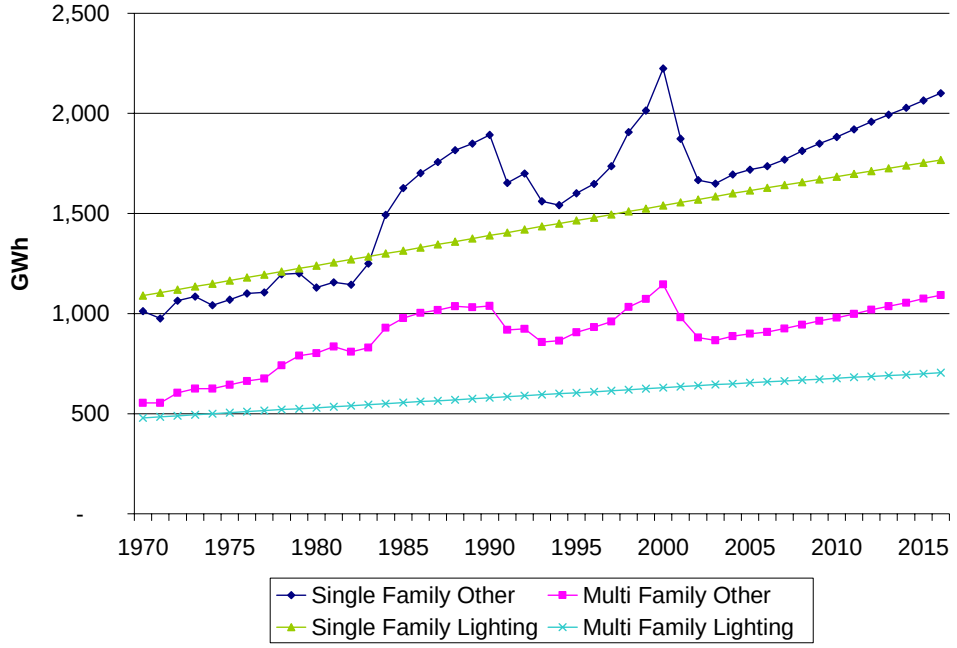
As noted above, the lighting end use has historically been embedded within the Energy Commission's "Miscellaneous" category. Much of lighting is essentially a plug load, like many other appliances in the Energy Commission's "Miscellaneous" end use. There are many lighting units in a household of varying wattage and usage characteristics. However, lighting technology is a dynamic area for energy efficiency improvements and has been a focus of policy interventions. As a result, for this study it was important to disaggregate lighting use from the rest of the Energy Commission's "Miscellaneous" end use.

Estimates of average residential lighting consumption in California generally range from 1,200 kWh per year to 1,600 kWh per year or more (CEC 1999). Recent residential on-site surveys, conducted as part of the California Statewide Lighting and Appliance Saturation Study (CLASS), estimated the number of lamps per home at roughly 33.8 in 2000 (RLW 2000) and 40.6 in 2005 (RLW 2005). Average hourly usage per lamp also has been measured periodically as part of utility program evaluations, with results indicating that hours of use vary widely across applications (e.g., room type). A recent monitoring study of compact

fluorescent lighting (CFL) applications estimated roughly 2.3 hours of use per day (KEMA 2005). However, applying that average hourly value to the installed wattage found in the 2005 CLASS would yield an average UEC of 2,071 kWh per year, which is outside the range of generally accepted average lighting UEC estimates. It is likely that the hours per fixture estimated in the KEMA-XENERGY (2003) and prior utility monitoring studies are associated with fixtures that are generally used actively. High-use fixtures are generally in kitchens, bathrooms, outside porches and high-use living spaces (Siminovitch, pers. comm. 2005). It may also be the case that the number of fixtures per home was overestimated in the 2005 CLASS. The 2000 CLASS fixture total was similar to that estimated in CEC (1999), while the 2005 CLASS estimate is considerably higher. On the other hand, as discussed below, there is also strong evidence that service demand for residential illumination has been increasing, possibly resulting in increased lighting UECs, despite increased penetration of CFLs.

Anecdotal evidence suggests that the amount of lighting energy has increased over time, due to an increase in home size, preference for increased illumination, and the increased use of recessed cans. The increase in fixtures associated with the change between the 2000 and 2005 CLASS reports represents a 4 percent annual increase. Over the same time period, based on CLASS, the installed household lighting wattage increased from 2,116 watts to 2,491 watts, representing a 3.5 percent annual increase. These figures take into account the reduced wattage per lamp that occurred as the saturation of CFLs increased over that time period. The number of CFLs per home increased from an average of 0.3 in the 2000 CLASS to 3.5 in the 2005 CLASS. The increase in the number of CFLs during the five years between lighting saturation studies offers strong evidence of efficiency improvement. If these data are correct, unless average hours of use decreased over the same period, the increase in lamps and wattage would mean that total lighting energy is increasing, despite the increase in saturation of CFLs.

As with much of the other data in used in this study, the challenge with the lighting end use was to integrate disparate data from non-comparable sources to develop a reasonable initial estimate of lighting consumption and analysis of changes over time. Based on analysis of all of the available data and sources, the average lighting UEC in 2004 was estimated at 1,600 kWh per year for single-family homes and 900 kWh per year for multifamily homes. The research team further estimated that the lighting UEC has been growing historically by roughly 15 kWh per year or about 1 percent annually for single-family households and 5 kWh per year or about 0.8 percent annually for multifamily households. Figure 3-3 shows this study's estimate of lighting trends versus "Other" end uses.



*The "Other" end use category includes electricity for solar water heating, electricity for solar water heating system pumps, electricity for swimming pool heating, electricity for swimming pool solar heating backup, waterbeds, evaporative coolers, and the Energy Commission's "Miscellaneous" end use, excluding lighting.

Figure 3-3: Estimated lighting usage trends versus "other"*

3.5. Sources for Efficiency Potential Estimates

Long-term energy efficiency potentials were estimated by end use, using a variety of sources—a complete list of which is provided at the end of this report. The rationale for each of the long-term efficiency potential improvements is presented by end use in Section 5. In general, the key sources were existing studies and interviews with technology experts. Key existing sources included energy efficiency potential studies (e.g., Rufo and Coito 2002), emerging technology studies (e.g., PIER 2005a through 2005l; ACEEE 2004), and other long-term forecasting efforts (e.g., Rong et al.. 2005; Ghanadan and Koomey 2005). More emphasis was placed on the results from the interviews (Bourne, pers. comm. 2006; Siminovitch, pers. comm. 2005; Calwell, pers. comm. 2005; Lutz, pers. comm. 2005; Sharp, pers. comm. 2006) since these experts were asked specifically for their opinion on end-use efficiency and service demand levels over the time frame of this study (i.e., out to 2050).

4.0 Development of Scenarios

The key the purpose of this study was to develop a methodology and set of initial results to assess what effect energy efficiency could have on residential electricity consumption by 2050. Alternative forecasts of residential electricity consumption are important inputs to climate change models that assess total GHG emissions and the relative costs and benefits of alternative emission reduction strategies.

As discussed in Section 2, it was decided early in this study that scenario analysis would be used as the principal organizing framework for this study. Rather than attempting to model adoption of individual energy efficiency measures far into the future, the research team decided to estimate average unit energy consumption levels in 2050 as a function of changes in end-use efficiency and utilization levels relative to today. As shown in Section 2, total energy consumption was obtained by interacting average end-use consumption with the total number of homes in each segment and associated electric end-use saturation levels. For this study the research team developed a variety of scenarios to assess the influence of population, end-use saturation increases, land use and housing development changes, and efficiency increases on future electricity consumption.

As discussed below, the research team developed two primary scenarios the Optimistic Efficient Technology scenario and the Green Dream scenario—to assess the potential effect of efficiency improvements and their corresponding policy implications. Two Frozen Efficiency forecasts were also developed to provide points of comparison with the efficiency improvement scenarios.

Several factors underlie this study's scenario analysis, including the trajectory of technology innovation, changing levels of desire for each end-use service, changing prices of end-use technologies, changing costs of electricity supply, and changes in the general state of the economy. Each of these factors is discussed in the remainder of this section and in Section 5. The discussion begins with the general scenario definitions and exogenous scenario inputs such as population growth. That is followed in Section 5 with a more detailed discussion of the end-use specific efficiency scenarios and the electric saturation scenarios.

4.1. Global Assumptions

Energy consumption is strongly correlated with economic activity; however, this study was not designed to predict a future economic conditions but rather to isolate the potential impacts of energy efficiency improvements on reducing future electricity consumption for the purpose of informing the state's research on GHG emissions and mitigation strategies. To this end, several alternative future scenarios were developed to explore how changes in key electricity drivers could affect residential electricity consumption over the next 45 years. The following guiding assumptions were used in this study's modeling and scenario development:

- A stable economy with no major economic collapse.
- Reductions in UECs result from improvements in technology efficiency rather than decreases in desired energy service levels. People will continue to have and use home lighting, appliances, and indoor air temperatures at least on par with what they have

today, and they will increasingly use technologies for information, communication, and entertainment.

- People in 2050 will be essentially the same as people today. They will continue to act more or less in their own self-interest, as it is perceived today. The balance between long-term self-interest and short-term self-interest will continue to be reflected in implicit consumer discount rates similar to those observed today.
- California will have a similar mix of socioeconomic classes in approximately similar distributions to those present today. Income levels within each of these socioeconomic classes will be similar in scale and diversity as are present today.
- Innovation and subsequent product development will be similar in scale and scope to today, yielding increasing utilization of electricity-consuming products and advancements in efficiency.
- Like today, large numbers of people will choose the least-cost product that fills their basic needs.

4.2. Overview of Scenarios

This section presents a general introduction to the scenarios developed. More detail on the end-use level efficiency and saturation scenarios is presented in Section 5. The primary focus of this study is on development of the efficiency scenarios. Other scenarios are developed to provide simple alternative forecasts of key exogenous drivers of total electricity consumption such as population and housing density. In addition, a simple forecast of residential photovoltaic (PV) market penetration is included to assess the potential impact of an aggressive combined package of PV and energy efficiency on total residential electricity consumption.

4.2.1. Efficiency Scenario Definitions

This section provides a general description of each electric efficiency scenario along with some of the possible associated policy implications. Efficiency scenarios for individual end uses are presented in Section 5.

4.2.1.1. Frozen Efficiency Forecast Scenario

Description: This scenario provides a baseline scenario in which there are no further improvements in efficiency levels on the margin (i.e., efficiency levels are generally frozen at the marginal UECs for 2006 in the Energy Commission end-use forecast). Reductions in some average UECs still occur over time due to the natural turnover of technologies and housing stock and the resulting shift from average to marginal UEC in homes. Utilization increases resulting from increased demand for energy services, which increases some UECs, are also included in this scenario, as described further below.

Policy Implications: This scenario by definition assumes no further policy or market innovations from 2016 to 2050. This scenario is developed primarily for the purpose of providing a reference to which the non-frozen efficiency forecasts can be compared.

4.2.1.2. Optimistic Efficient Technology (OET) Scenario

Description: The OET scenario assumes significant penetration of energy-efficient technologies that will be at or near the edge of cost-effectiveness in 2050 but still become

widely adopted. It assumes that the cost of energy will grow in real terms over time but within a magnitude and rate that can be absorbed by the economy without a major disruption or restructuring of the California lifestyle relative to the cycles and within the variance that has been experienced over the past 50 years. The research team considers the underlying end-use UEC forecasts for 2050 to be optimistic within the range of status quo economic and political constraints assumed.

Policy Implications: California will pursue policies consistent with, or slightly more aggressive than, those presently in place. There will be periodic updates to energy efficiency standards, enforcement of those standards, and support of utility efficiency programs. Attempts will be made to capture all cost-effective energy efficiency opportunities.

4.2.1.3. Green Dream Scenario

Description: This scenario assumes the adoption of the most energy-efficient technologies expected to be available over the forecast period within existing technology paradigms. Technologies adopted in this scenario are not necessarily expected to be cost-effective. The Green Dream scenario purposefully pushes the envelope of what could be expected from efficiency improvements and associated policies absent significant technological and socioeconomic paradigm shifts.

The Green Dream scenario tests the impacts that technology and policy can have on reducing energy consumption. It is not intended to be utopian or have embedded social restructuring as a requirement. However, any social change necessary to achieve the political will required to enact policies supporting this scenario presents a barrier and cannot be assumed. Individual UEC forecasts are provided in Section 5.

Policy Implications: California would have to pursue polices that give preference to energy efficiency over other issues. Appliance and homebuilding efficiency standards would need to be much more stringent and rigorously enforced. It is likely that a significant carbon tax or other price effect would be needed to shift resources and stimulate the implementation of cutting-edge energy efficiency measures. Incentive and/or disincentive structures would be called for to promote such measures as smaller home sizes, construction methods that employ greater insulation and infiltrations standards, enforced passive cooling and shading in hot regions, the elimination of oversized air conditions, required periodic HVAC maintenance, improved ducting design and installation, refrigerator size constraints, the elimination of second refrigerators, more daylighting in home design, the elimination of standard efficiency light bulbs and effective light controlling sensors for all indoor and outdoor light fixtures.

4.2.2. Electric Saturation Scenarios

Two residential electricity saturation scenarios were investigated, one in which saturations are capped at their 2006 levels, and one that assumes modest continued increases over the forecast horizon.

4.2.2.1. Static Saturation Benchmark

For this benchmarking scenario it is assumed that the saturation for each end-use stays the same as it is in 2006, as modeled by the Energy Commission. This benchmark is used only

for the analytic purpose of estimating the contribution of continued changes in electric end-use saturations on total consumption by 2050.

Policy Implications: Static electric saturation of all end uses through 2050, though possible, is unlikely and no policy has been described that could be used to improve the likelihood of this result.

4.2.2.2. Continued Electric Saturation Diffusion Trend

This scenario assumes the continuation of trends observed in the historic and forecast Energy Commission end-use saturation data with some minor adjustments based on interviews with industry experts. For many end uses with historically high electric saturation growth rates, it is assumed that the rate of growth will flatten soon after the end of the Energy Commission's forecast period, in 2016. The end-use specific saturation forecasts are provided in Section 5. This saturation scenario is used in all of the primary efficiency scenario results presented in Section 6.

Policy Implications: This scenario implies no further changes in policies related to electric end-use saturation.

4.2.3. Population Scenarios

4.2.3.1. Baseline California Department of Finance Estimate

Description: This scenario uses the CADOF estimate for the forecasted 2050 population for each county (CADOF 2006). Application of the CADOF forecast to this study is discussed in Section 3.

Policy Implications: This study focuses on energy efficiency scenario analysis and policies. The population forecasts are considered exogenous factors. Population-related policy implications are outside the scope of this study.

4.2.3.2. Landis et al., California Urban Footprint 2100

Description: The population projections for 2050 in the study titled, *How We Will Grow: Baseline Projections of California's Urban Footprint through 2100* (Landis and Reilly 2003), is an alternative basis for population estimates for both California's total population and for the distribution of the population by county in 2050.

Policy Implications: This study focuses on energy efficiency scenario analysis and policies. The population forecasts are considered exogenous factors. Population-related policy implications are outside the scope of this study.

4.2.4. Housing Density Scenarios

4.2.4.1. Baseline Housing Density

Description: This scenario assumes that the current mix of single-family and multifamily dwellings will remain the same.

Policy Implications: No further policy efforts to encourage of shift the ratio of single-family to multifamily homes or density of multifamily units.

4.2.4.2. Increased Housing Density

Description: This scenario assumes that for new construction in each climate zone, half the assumed new single-family dwellings will be built as multifamily dwellings starting in 2006. For example, if presently 80 percent of new homes are single-family dwellings, for the forecast period (2006–2050) 40 percent of new homes built will be single family and 60 percent will be multifamily. Because the ratio of single-family to multifamily varies widely across market segment (see Section 3), this adjustment is made for each market segment.

Policy Implications: Major land use development policy changes would be required immediately.

4.2.5. Photovoltaic Scenarios

Although energy efficiency scenarios are the core analytical objective of this study, it was considered useful to also estimate the potential impact of increased market penetration of rooftop PV systems on future residential electricity consumption, even though residential PV is usually considered a supply-side alternative. The purpose of this scenario in the context of this study is not to defend these PV forecasts analytically, but simply to apply a wide range of possible penetration levels to assess the potential combined effect of efficiency and rooftop PV.

The California Solar Initiative (CSI), approved in early 2006, is a key policy underlying this scenario. The CSI is designed to provide rebates to homeowners, businesses, farmers, and government projects investing in rooftop photovoltaic systems, with a goal of installing 3,000 megawatts (MW) of solar power over the next 11 years. For this analysis the impact of achieving two million and five million households with photovoltaic systems by 2050 is considered.

This analysis assumed an average photovoltaic system with a 2.5 kW rated capacity that operates an average of five hours per day, 365 days per year, with a 35 percent shading loss (Sharp, pers. comm. 2006). The average yield is thus 2,966 kWh per year.

4.3. End-Use Service Demands

The forecast UECs for 2050 account for changes in both technology efficiency and end-use service demands. End-use service demands can increase or decrease in many different ways; however, the trend for most end uses is toward increases. For example, an increase in energy service demand for lighting could manifest as a function both of increased home size and increase in the amount of illumination desired per square foot of home size. Similarly, increased service demands for space conditioning can likewise increase with home size or due to a desire to increase the difference between indoor and outdoor temperatures. Note that saturation-related effects of end-use service demand are captured through the saturation scenarios. The utilization factors discussed in this section capture changes in end-use service demand among those homes that have the end use present. Countervailing effects of increases in energy efficiency are modeled separately as discussed in Section 2 and Section 5.

In an effort to disaggregate the components that comprise the UEC, this section presents study assumptions about how end-use service demands will change between the present and 2050. The research team developed the changes in energy service levels by analyzing

historic trends and making relatively conservative estimates about how they may increase in the future. For some end uses, the change in service demand was derived from a linear extrapolation of the rate of annual growth of the Energy Commission's marginal UEC forecasts (for 2006 to 2016). For these end uses, this study's estimates of increased utilization are conservative if there are embedded efficiency improvements in those UECs. Other estimates of changes in utilization were based on analysis of historical trends, secondary sources, and interviews with technology experts. This approach was used in cases where there was strong evidence of increases in utilization from sources other than the Energy Commission's 2006 to 2016 forecast. The research team's approach for those end uses is discussed below. Table 4-1 summarizes the resulting changes in service demand.

Table 4-1: Assumed relative changes in energy service for residential electric end-uses from 2006 to 2050 by dwelling type (100% = 2006)

	2050 End-Use Service Demand Relative to 2006 (100%=2006 energy service demand)	
End Use	**Single Family (%)**	**Multifamily (%)**
Water Heating	102	100
Dishwasher	106	100
Water Heating - Dishwasher	108	107
Clothes Washer	105	100
Water Heating - Clothes Washer	108	107
Clothes Dryer	106	94
Other	150	160
Cooking	106	100
Refrigerator	110	105
Freezer	100	100
Swimming Pool Pump	99	100
Hot Tub Pump	102	NA
Hot Tub Heating	102	NA
Lighting	110	105
Space Heating	110	105
Furnace Fan	110	105
Central Air Conditioner	110	105
Room Air Conditioner	110	105

4.3.1.1. Space Conditioning

This study assumes that people in 2050 will operate their heating and cooling systems in ways similar to today, and keep their living spaces within similar temperature ranges. Electric energy use for space conditioning will increase with home size, all other factors being equal. As discussed previously, new homes are forecast to be larger than existing homes and many existing homes will have additions built that will increase their size. However, note that the rate of increase in home size the research team assumed is far less than what has been observed for the past 50 years. As discussed in Section 3, the team assumed that the trend toward larger homes will plateau over the next 50 years. As a result

of the expected increase in home size, the team also estimated that the average single-family household in 2050 will require 10 percent more space conditioning, as compared with today and that the average multifamily household will require 3 percent more. Note that no impact that climate change might have on heating and cooling loads is included.

4.3.1.2. Lighting

Over the past several decades, Californians' have desired increasing levels of illumination in their homes (see the lighting discussion in Section 3). Based on the trends of both increasing levels of illumination and increasing home size, lighting utilization is forecasted to increase through 2050 by 10 percent for single-family and 5 percent for multifamily households, relative to present lighting levels.

4.3.1.3. Refrigeration

Refrigerators have grown significantly in size and energy-consuming features over the past 25 years. Over the same time period, efficiency has also increased significantly, with the net result being substantial reductions in consumption per unit. The research team assumes that the average single-family refrigerator service demand will be 5 to 10 percent greater in 2050, as the result of further increases in size and features.

4.3.1.4. Other

According to the Energy Commission (CEC 2005b), the "Miscellaneous" end-use has grown rapidly and has had far more impact on the growth of electric energy consumption than any other end use over the past 25 years. While most other UECs have declined over this period, the miscellaneous UEC has grown significantly. The Energy Commission forecasts that this historic rate of growth to continue to 2016. For 2017 through 2050, a growth rate for miscellaneous usage was used that is half the average historic and Energy Commission forecast growth rate after removing lighting energy consumption. In decreasing the rate of growth in the miscellaneous usage from its historic average, it is assumed that new products will continue to be introduced and adopted, but that these products will start to displace older more energy-consuming items rather than presenting completely new loads. For example, over the past 10 years products like home computers, cell phones, printers, faxes, set-top boxes, and other electronic devices have added significant new incremental loads to residential homes. However, there is some indication that these devices may be consolidated in the future into fewer products that also displace older pieces of equipment (e.g., the traditional home stereo). On the other hand, other factors could just as easily cause a continuation of the historic rate of growth for this end-use.[8]

[8] For example, consumer desire for greater convenience shows no sign of ebbing and may be increased by the demands of an aging population that may give rise to a proliferation of yet more plug-in products such as exercise equipment, home and health monitoring equipment, electric ice pads, climate-controlled cabinets for special purposes, new home atmosphere altering technologies, and personal transport vehicles.

5.0 Retrospective End-Use Review, Development of Future UEC, and Saturation Scenarios

This section presents a discussion of each residential electric end use and how it is expected to change by 2050 under both the OET and Green Dream scenarios, given the study's estimates of changes in utilization and efficiency. This discussion focuses on efficiency-related changes, which are summarized in Table 5-1. Changes in end-use service demand are discussed in Section 4. Non-space conditioning end uses are discussed first followed by heating and cooling. Note that after each of the end uses is discussed, a summary is provided that presents the research team's forecasts of these UECs out to 2050 under the OET scenario.

Table 5-1: Assumed marginal efficiency levels for residential electric end uses in 2050 relative to 2006 by scenario and dwelling type

	2050 End-Use Marginal Efficiency Relative to 2006 (100% = 2006 Efficiency Level)			
	Optimistic Efficiency Technology		Green Dream	
End Use	Existing (%)	New (%)	Existing (%)	New (%)
Water Heating	95	95	50	50
Dishwasher	100	100	70	70
Water Heating - Dishwasher	95	95	50	50
Clothes Washer	105	105	110	110
Water Heating - Clothes Washer	80	80	35	35
Clothes Dryer	70	70	50	50
Other	90	90	80	80
Cooking	100	100	90	90
Refrigerator	80	80	40	40
Freezer	80	80	50	50
Swimming Pool Pump	90	90	80	80
Hot Tub Pump	95	95	90	90
Hot Tub Heating	95	95	90	90
Lighting	80	50	30	30
Space Heating	90	90	70	70
Furnace Fan	95	90	80	80
Central Air Conditioner	80	65	60	30
Room Air Conditioner	90	90	70	70

5.1. Water Heating

Like other heating end uses, electric water heating is generally a relatively minor consumer of total residential energy for California, due to the widespread use of natural gas (Sharp, pers. comm. 2006). In 2005, electric water heating accounted for less than 6 percent of California's residential electric load. Key contributors to electricity consumption for water heating are standby losses, pipe losses, and hot water demand. Hot water demand is driven primarily by bathing, washing, clothes washers, and dishwashers. The electric water heating in this analysis includes water heating for clothes washing and dish washing. The Energy Commission's estimates of water heating UECs for customers with electric water heating are shown in Table 5-2.

Table 5-2: CEC estimates of water heating UECs

	Single Family	Multi Family
Water Heating - General	2,225	1,795
Water Heating - Dishwasher	938	716
Water Heating - Clothes Washer	1,070	905

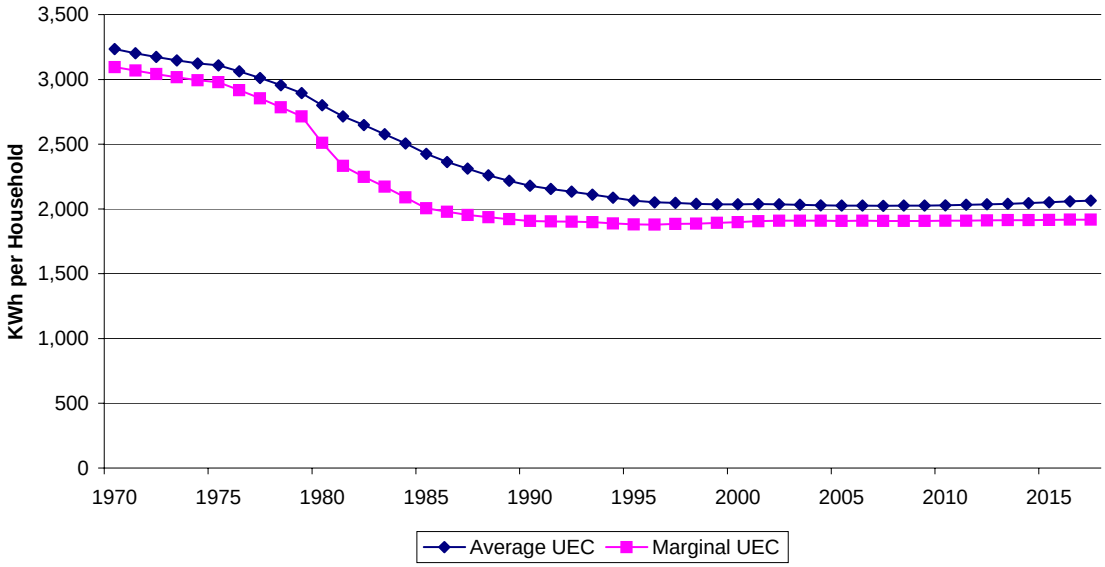
Almost all electric water heaters use electric resistance technology. Present day electric water heaters are 90 to 95 percent efficient, including tank losses (ACEEE 2006). The water-heating element is almost 100 percent efficient. Losses are introduced primarily through thermal leakage both when hot water is standing by in the tank and when transferred through pipes. Modern water heaters have sufficient insulation to make standby losses fairly small. Instantaneous water heaters reduce standby losses even further. This technology heats a large quantity of water in a short time, creating significant electric power demand. While instantaneous water heaters are popular in Europe, they have not gained much favor in the United States, although there is some indication penetration may increase. Water heating demand from showers and faucets has been reduced in California through standards and programs supporting low-flow showerheads and aerators.

Heat pump water heaters are about three times as efficient as resistance water heaters and cost many times more. This is a known technology that might become cost effective and thereby increase its market penetration in the future, provided that corrosion of the water-side heat exchanger is addressed (Lutz 2005). There are currently no major manufacturers of heat pump water heaters, although there are boutique producers. The technology has been of interest to energy efficiency planners for over ten years but has had difficulty achieving market acceptance due to its high cost and potential maintenance issues associated with corrosion.

Solar water heating also can provide significant reductions in electricity consumption for water heating. However, solar water heating payback periods are currently high and, as a result, solar water heating market share is relatively low.

As noted above, clothes washers and dishwashers also contribute directly to hot water consumption. According to the Energy Commission's end-use data, presently clothes washers consume about 26 percent of the electricity used to heat water, while dishwashers consume about 17 percent. Horizontal axis clothes washers offer some water heating energy savings by virtue of using less water overall. The energy savings are directly related to how much hot water is used for clothes washing. High efficiency dishwashers also save energy by reducing the amount of water used in washing (ACEEE 2006). However, most of their energy saving potential is tied to eliminating the drying cycle.

As shown in Figure 5-1, the marginal UEC for general water heating (i.e., excluding clothes washers and dishwashers) dropped until the mid-1990s and then was generally flat. The Energy Commission predicts that the UEC for water heating will remain relatively flat in the near future.



*Exclusive of water heating load associated with clothes washers and dishwashers.

Figure 5-1: Electric water heating* average and marginal UECs weighted average for all households with technology

5.1.1. Optimistic Efficient Technology Scenario, Water Heating

The OET scenario assumes limited increase in the use of heat pump water heaters, and that resistance water heaters will continue to dominate the electric water heater market. Losses will be reduced through more efficient hot water usage by other technologies. Marginal efficiency for general water heating will improve by 5 percent due to increased insulation of hot water tanks and the increased use of instantaneous water heaters. A 5 percent efficiency improvement was assumed for the marginal efficiency for water heating for dishwashers. This scenario also assumes 50 percent saturation of horizontal axis clothes washers. As a result, the water heating savings for clothes washing hot water is forecast to be 20 percent less than the current marginal consumption.

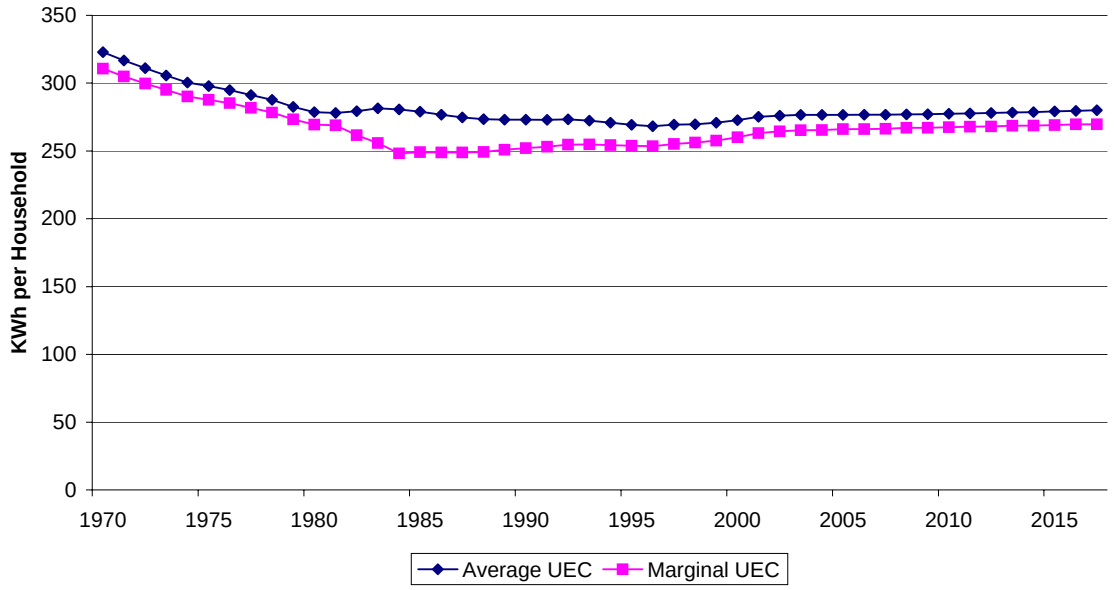
5.1.2. Green Dream Scenario, Water Heating

The Green Dream scenario water heating UEC depends on high saturation of heat pump water heaters and solar water heating. All home hot water piping will be insulated. Heat recovery to preheat water will be used when possible. Overall hot water system efficiency will improve by 50 percent. The same reduction is applied to electric water heating for dishwashers. This scenario also assumes 100 percent saturation of horizontal axis clothes washers, which is estimated to improve the efficiency of clothes washing hot water by 65 percent.

5.2. Dishwasher

As discussed under water heating, the electric water heating load for dishwashers is addressed as part of the electric water heating end use. The dishwasher end use presented here addressed the dishwater motor, water heater booster, and heating for drying. As shown in Figure 5-2, the dishwasher marginal UEC decreased somewhat until the mid-

1980s, has been rising modestly since, and is forecast by the Energy Commission to continue to rise modestly. The major energy saving innovation for dishwashers in the last 30 years (excepting the water use reductions addressed previously) has been the ability to turn off the heat on the drying cycle.



*Excludes electricity use associated with source water heating.

Figure 5-2: Dishwasher* average and marginal UECs weighted average for all households with technology

5.2.1. Optimistic Efficient Technology Scenario, Dishwasher

No technology breakthrough to improve dishwasher motor, booster, or drying efficiency is expected. The OET scenario assumes the same dishwasher efficiency in 2050 as today.

5.2.2. Green Dream Scenario, Dishwasher

The Green Dream scenario for dishwasher UEC depends on eliminating the drying cycle or replacing it with something other than resistance heating. Resistance heating will still be used to boost water temperature in the wash cycle. The efficiency savings will result in a 30 percent reduction in energy consumption.

5.3. Clothes Washer

As discussed under water heating, the electric water heating load for clothes washers is addressed as part of the electric water heating end use. The cloths washer end use presented here addressed the clothes washer motor. The clothes washer motor UEC has been relatively flat, with a slight rise estimated by the Energy Commission since the early 1980s, as shown in Figure 5-3. An increased UEC would most likely be the result of increased usage as people take advantage of special delicate cycles and wash a greater number of smaller loads. The recent technology advances in horizontal axis washers mostly save water and detergent but not much motor energy. Higher efficiency clothes washers, as estimated using the modified energy factor (MEF), also utilize higher spin speeds to reduce moisture

before drying. High spin-speed washers reduce the moisture content of washed clothing. The high spin speed reduces drying time but uses more motor energy.

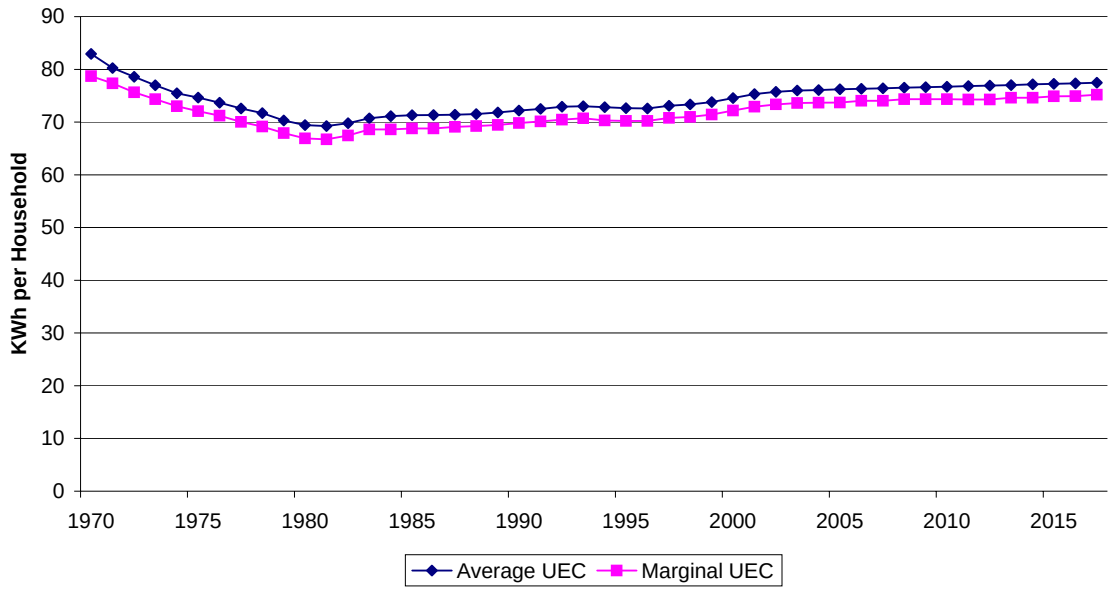


Figure 5-3: Clothes washer average and marginal UECs weighted average for all households with technology

5.3.1. Optimistic Efficient Technology Scenario, Clothes Washer

The OET scenario assumes a 5 percent increase in washer motor energy consumption by 2050 due to continued increases in spin speed.

5.3.2. Green Dream Scenario, Clothes Washer

As noted in the water heating discussion, only high efficiency horizontal axis washers with high-efficiency motors will be available in the Green Dream scenario. Thus, the clothes washer motor UEC will likely increase due to the higher spin rates. The UEC will increase by 10 percent from the current level.

5.4. Clothes Dryer

According to Energy Commission estimates, the electric clothes dryer UEC has been increasing since the early 1980s, as shown in Figure 5-4. As with other heating technologies, natural gas is the preferred fuel in California, although the saturation of electric drying is significant. Electric clothes dryer have 37% market share in California, while the share for natural gas is 47%. Although many alternatives to electric resistance heating have been under consideration for clothes drying for the past 25 years, including heat pumps and microwave technology, there is no evidence that these technologies will replace resistance heating. Moisture sensors are a feature already available for most dryers that can slightly reduce drying time. The best pathway for reducing the dryer UEC is increasing the market share of higher spin-speed washers, as discussed previously.

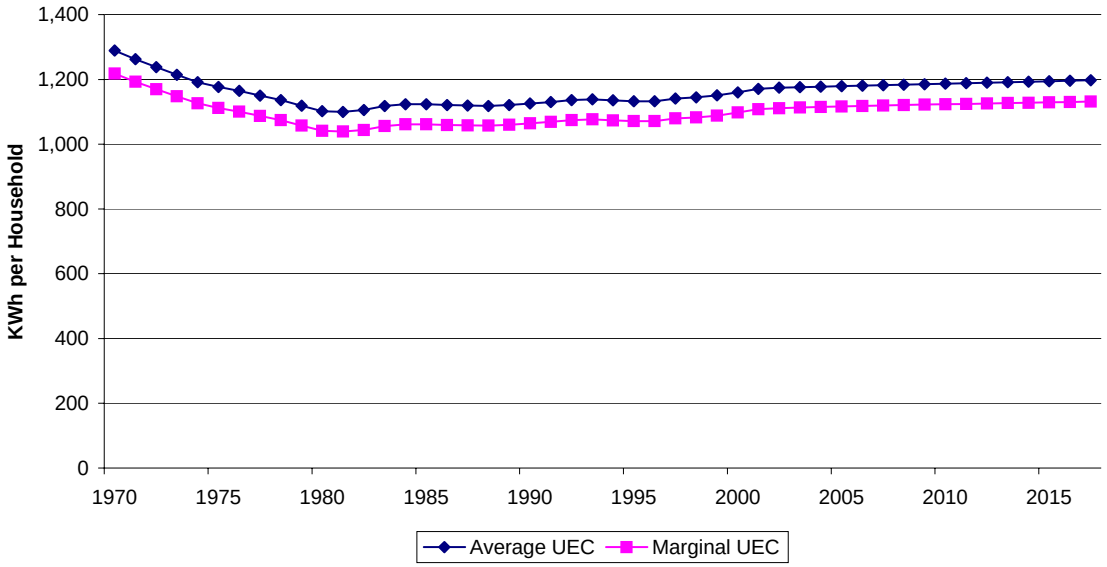


Figure 5-4: Clothes dryer average and marginal UECs weighted average for all households with technology

5.4.1. Optimistic Efficient Technology Scenario, Clothes Dryer

The OET scenario assumes 30 percent efficiency improvement in clothes drying due to the increased saturation of higher spin-speed washers and better clothes dryer moisture sensors.

5.4.2. Green Dream Scenario, Clothes Dryer

In the Green Dream scenario, the electric clothes dryer energy use will drop as a result of the lower moisture content in clothing resulting from a complete penetration of high spin-speed washers. In addition, dryers will have better moisture sensors. Resistance heating will still be used due to temperature requirements. The result will be a 50 percent efficiency improvement.

5.5. Cooking

Figure 5-5 shows that the Energy Commission's estimates of marginal and average cooking UECs have been rising since the early 1980s and are forecast to continue to rise. The most significant energy efficiency improvement within electric cooking is induction technology. However, this technology has been available for many years and is far from cost effective. Convection ovens also offer some modest efficiency gains. Additional, very modest, improvements are possible through changes in cooking behavior (ACEEE 2006).

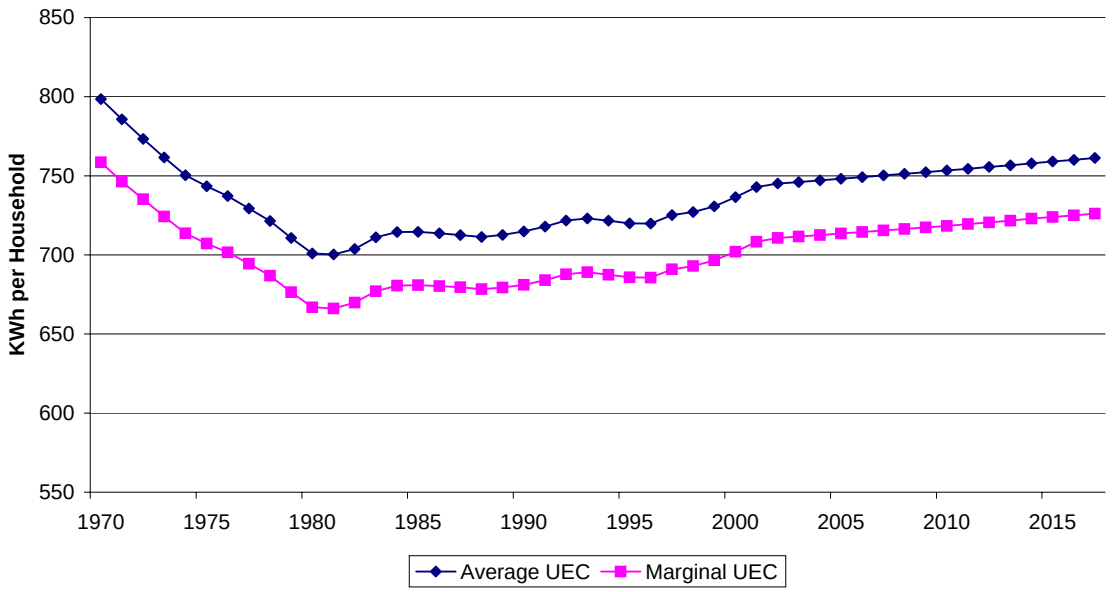


Figure 5-5: Cooking average and marginal UECs weighted average for all households with technology

5.5.1. Optimistic Efficient Technology Scenario, Cooking

The OET scenario assumes that there are a few technologies like induction stove tops that have the potential to offer reductions in cooking energy but at considerable expense. They are more likely to be used in commercial applications and wide acceptance of these technologies in residential cooking is not expected. No reduction in the electric cooking UEC is assumed for the OET scenario.

5.5.2. Green Dream Scenario, Cooking

Little can be done to improve the cooking UEC from a purely technological standpoint. However, there is great variety in cooking energy consumption depending on how one cooks. In the Green Dream scenario, cooking efficiency could be improved by 10 percent through a highly effective information campaign on cooking practices.

5.6. Refrigerator

Figure 5-6 shows an initial rise in the average UEC for refrigerators as people shifted from manual defrost to frost-free units in the 1970s. The marginal UEC declined until the early 1990s as a result of appliance standards and efficiency programs. Since then, refrigerators have continued to grow in size and to incorporate more energy-consuming features like through-the-door ice access. Nonetheless, efficiency improvements have more than outpaced increases in service demand. The average refrigerator UEC has continued to decline and the Energy Commission forecasts that it will continue to do so. However, the marginal UEC is flat out until 2016 in the Energy Commission's current forecast. Future efficiency improvements in refrigerators remain possible, however, the cost effectiveness of these improvements has been and may continue to decrease due to the fact that there is less energy (and dollars) to save as total consumption is reduced.

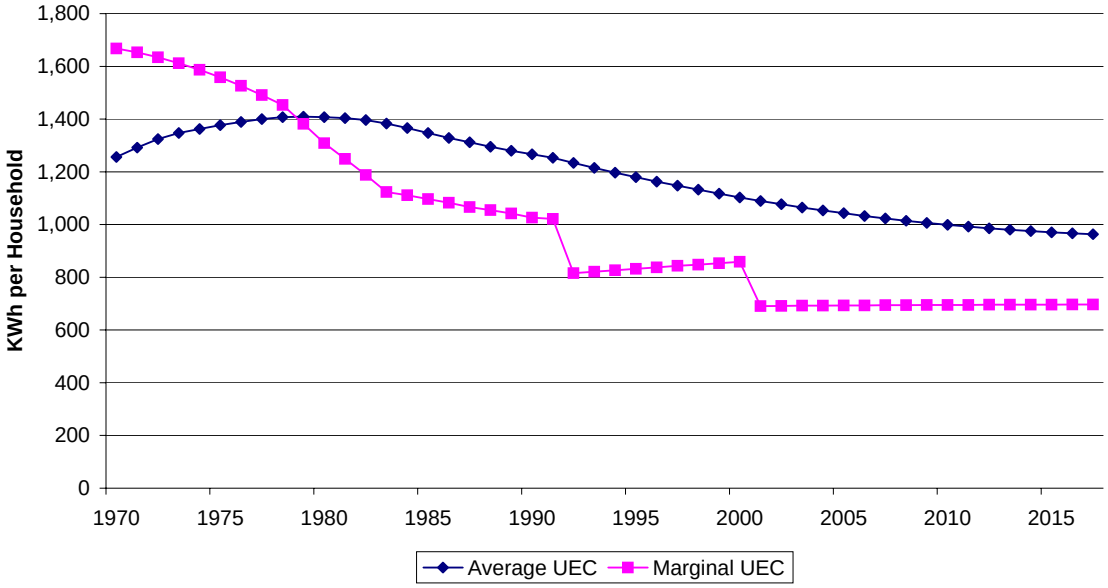


Figure 5-6: Refrigerator average and marginal UECs weighted average for all households with technology

5.6.1. Optimistic Efficient Technology Scenario, Refrigerator

The OET scenario assumes that efficiency standards will further reduce energy consumption and that average savings on the margin will improve by another 20 percent by 2050 through a combination of more efficient compressors and increased insulation in refrigerators.

5.6.2. Green Dream Scenario, Refrigerator

In the Green Dream scenario refrigerator insulation levels are further increased. As a result, average refrigerator efficiency will improve to 50 percent beyond current marginal efficiency levels.

5.7. Freezer

The freezer average UEC has been declining steadily since the early 1980s and is forecast to continue the trend, as illustrated in Figure 5-7. Freezer efficiency improvements have tended to follow those of refrigerators through the implementation of state and federal standards.

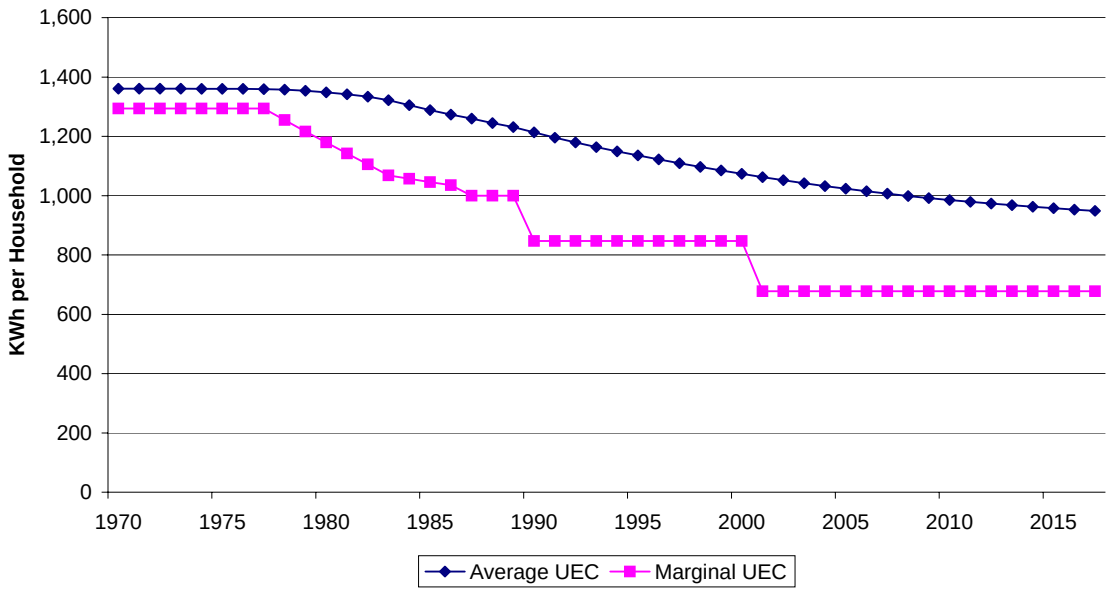


Figure 5-7: Freezer average and marginal UECs weighted average for all households with technology

5.7.1. Optimistic Efficient Technology Scenario, Freezer

The OET scenario assumes that efficiency standards will further reduce energy consumption and that average savings on the margin will improve by another 20 percent by 2050 through a combination of more efficient compressors and increased insulation in freezers.

5.7.2. Green Dream Scenario, Freezer

The Green Dream scenario assumes further increases in freezer insulation levels. As a result, average freezer efficiency will improve 50 percent beyond current marginal efficiency levels.

5.8. Swimming Pool Pump

The swimming pool pump average UEC has been declining and is forecast to almost reach the marginal UEC by 2016, as Figure 5-8 shows. The increased use of high-efficiency motors is the primary technology improvement anticipated to decrease the swimming pool pump UEC. Multiple-speed pool pumps are also now available and are being promoted in some utility programs. However, because they depend somewhat on behavior changes, there is some uncertainty in actual savings. Of more significance will be the size of pools in 2050 and the corresponding size of pump motors.

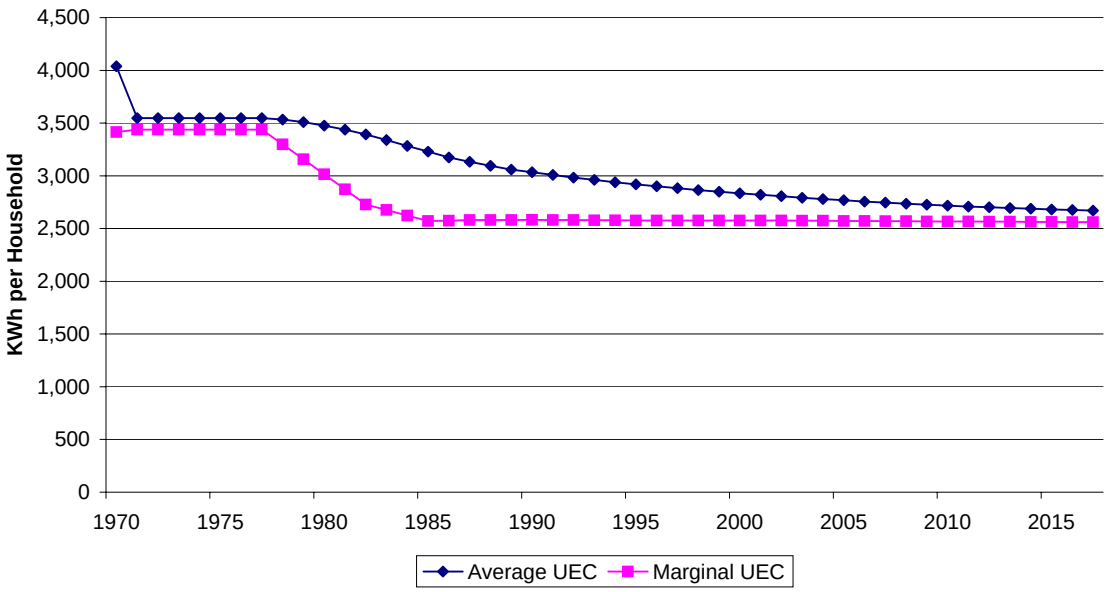


Figure 5-8: Swimming pool pump average and marginal UECs weighted average for all households with technology

5.8.1. Optimistic Efficient Technology Scenario, Pool Pump

The OET scenario assumes technology for pool pumping will be 10 percent more efficient in 2005.

5.8.2. Green Dream Scenario, Pool Pump

The Green Dream scenario assumes technology for pool pumping will be 20 percent more efficient in 2005.

5.9. Hot Tub Pump and Hot Tub Heating

According to the Energy Commission's data, hot tubs account for very little, roughly 1 percent, of residential electricity consumption. The UECs for both hot tub pumps and hot tub heating have been gradually increasing over time but only slightly.

5.9.1. Optimistic Efficient Technology Scenario, Hot Tub Pump and Hot Tub Heating

The OET scenario assumes that both hot tub pumping and heating technologies will be 5 percent more efficient by 2050. This can be accomplished with better insulation and pump controls.

5.9.2. Green Dream Scenario, Hot Tub Pump and Hot Tub Heating

The Green Dream scenario assumes that both hot tub pumping and heating technologies will be 10 percent more efficient by 2050. This can be accomplished with better insulation and pumps controls.

5.10. Other

The "Other" end use category includes all loads not specifically covered by the individual end uses discussed in this section. When considering the UEC for this amalgamation of uses, it is helpful to understand the range of products that contribute to the "Miscellaneous" category. These include electronics for home entertainment and home offices, household conveniences, and emerging home health-care products. There has been and it appears likely there will continue to be an increasing number and variety of electronic products utilized in the residential sector. In addition to their direct use of electricity during service, many of these products also require a power supply or power converter that continually consumes small amounts of electricity (Calwell 2005b, Ecos 2004).

Although significant effort is being made by the electronics industry to increase the energy efficiency of the devices it produces, according to industry experts, most of the impetus to reduce electric consumptions has little to do with the desire to save energy. Rather, the industry seeks to reduce waste heat because heat is the major cause of electronic product failure. There have been efficiency gains made for many electronic products and the research team assumes that more will continue to be made. However, energy savings from efficiency improvements are likely to be more than offset, in terms of total consumption, by increases in the energy demands associated with increases in technology size and features. For example, TVs are more energy efficient within a given size category, but the trend is toward much larger TVs and potentially ones with features that require continuous use (e.g., plasma wall units that function as photography or art displays when not in use as televisions). On the whole, given the gains in efficiency, the losses due to increased TV size, and the increasing number of TVs per household, the average household energy consumption for TVs has been increasing and will likely continue to increase. The situation is similar for other electronics such as computers. Although usage per computer continues to decrease (e.g., via use of flat monitors and laptops), the number of computers per home is also increasing. These trends will likely continue. Technical innovation will create more products with greater capabilities that result in increased power consumption. Simultaneously, efforts will be made to increase the efficiency of these products as they are developed.

Non-manufacturing groups representing energy efficiency interests are also trying to make electronics more efficient. There are three primary areas of focus: power supply inefficiency, battery charging inefficiency, and improved matching of energy consumption to work requirements (Calwell 2005b). In all three areas, the goal is to stop energy waste by using information feedback to throttle energy consumption to the appropriate levels for the work being done. It is expected that regulation, such as the 2007/2008 California standards for standby power, will play an important role in accomplishing these energy savings goals.

As discussed in Section 4, the research team estimates that the energy service demand for these Other end uses will increase by 50 percent by 2050. Thus, although the team also expects efficiency improvements in these devices, forecast total aggregate consumption for the Other category is expected to increase.

Figure 5-9 shows the estimates for the Other UEC for both single-family and multifamily households for the period 1970 to 2016. It also shows trend lines based on linear regression

of the Energy Commission's data. It is unlikely that the UEC will continue to grow at the historic rate through 2050. In this study's forecast of energy service demand for this end use, the research team assumes that growth will continue to be significant but will be slightly less than the historic rate shown in the figure.

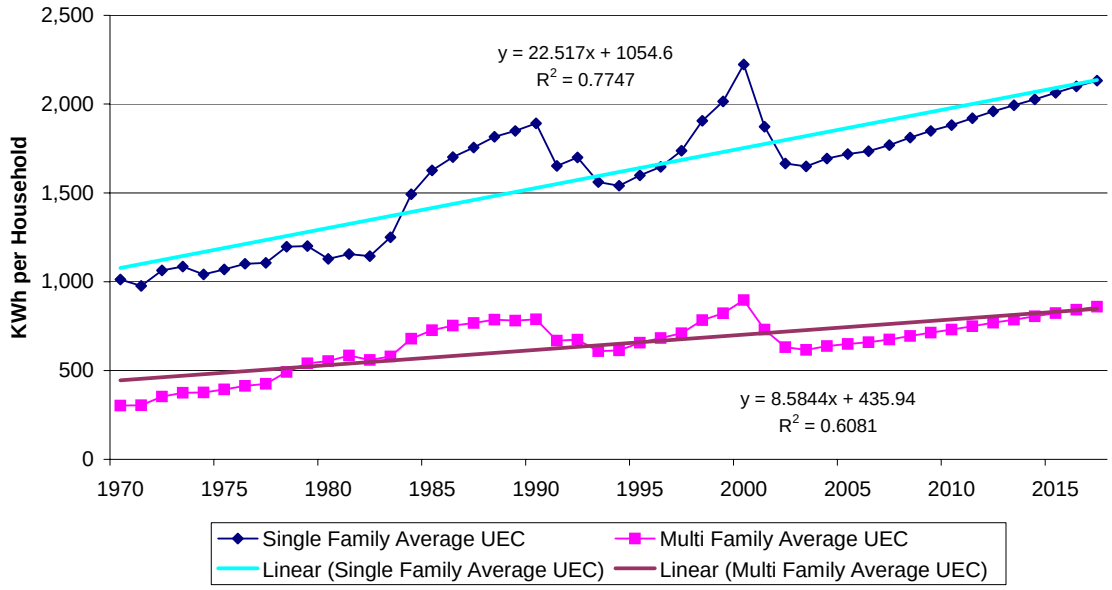


Figure 5-9: "Other" average UEC trends for single-family and multifamily households

5.10.1. Optimistic Efficient Technology Scenario, Other

The OET scenario assumes a 10 percent improvement in Other end-use technology efficiency by 2050. These savings will result from regulation and standards for power supplies and battery chargers, as well as other opportunities to match energy consumption with work load requirements.

5.10.2. Green Dream Scenario, Other

The Green Dream scenario assumes a 20 percent improvement in efficiency for Other end uses by 2050.

5.11. Lighting

As discussed above, the lighting UEC was estimated and disaggregated from the Energy Commission's "Miscellaneous" end use. Also discussed above, the present analysis indicates that the UEC for lighting has been growing as a result of an increase in home size and illumination levels. The increase in the UEC has been offset to some extent by significant increases in the use of CFLs (from less than 1 percent saturation in 2000 to almost 9 percent in 2005). Although CFLs are now found in many homes, they are not yet the preferred type of lighting and are in limited applications (roughly 3.5 bulbs per home).

Of all the residential end uses, lighting is perhaps the most dynamic and uncertain in its technology trajectory. Lighting differs because its basic science of energy packet emission

from reacting elements has not been fully explored. There are three general classes of lighting that could be used to improve efficiency in the residential sector:

- Incandescent/halogen
- Fluorescent/CFLs
- LED

Incandescent lighting remains the technology of choice for the residential sector due to its light quality and controllability. However, it is extremely inefficient. Nonetheless, some lighting experts predict a whole new generation of energy-efficient incandescent lighting based on the same principles used for halogen and induction lamps (Siminovitch, person. comm. 2005). Fluorescent/CFL technology has recently achieved more significant penetration in the residential sector, after languishing somewhat throughout the 1990s. There has been continued improvement in both energy efficiency and color rendition in fluorescent lighting and solid-state lighting over the past 10 years. However, despite product improvements, CFL quality and controllability remain below most residential consumers' expectations for the majority of applications. LED lighting, which is an extremely efficient but decidedly niche technology today, has been considered by some as a technology that could eventually be deployed in indoor applications (Rong 2006). However, not all lighting experts agree on the feasibility or timeline for such a transformation of this technology. Of course, daytime electric lighting use also can be decreased through the use of daylighting. Daylighting is expected to increase through the continued use of improved skylights or light tubes.

In the short term, the latest Title 24 standards functionally require higher efficiency (usually fluorescent) lighting for built-in fixtures in most rooms or better lighting controls. This should help to reduce the growth in lighting electricity consumption per home, even though many lighting devices are plug-in rather than built-in loads. However, there is evidence that compliance is sometimes skirted by contractors, particularly in the major renovation market which is also under the Title 24 requirements, who install fluorescent lighting fixtures to satisfy inspectors and then remove them and install different lighting fixtures to satisfy customers. Both improved lighting products and compliance enforcement will be critical for lighting energy reductions.

In the long term, the way lighting is used in the 2050 may be very different than today. In addition to the expected continuation of the trend toward increased illumination levels, there may be more mood lighting with different spectrums of light emphasized at different times of day. Lighting may emanate from surfaces rather than fixtures. Lighting efficiency may vastly increase as a result of one or more breakthroughs or continued gradual improvements in incandescent, CFL, or LED technologies. It is also possible that few breakthroughs occur and technology characteristics plateau at levels similar to today. In sum, although these potential trends may reduce lighting usage, it is also possible that lighting energy UECs could continue to increase.

5.11.1. Optimistic Efficient Technology Scenario, Lighting

The OET scenario assumes that residential lighting efficiency will improve by 20 percent for existing construction and 50 percent for new construction by 2050. The improvements will

be the result of building standards for increased efficiency and an array of new more efficient lighting products that are both cost-effective and produce light that is pleasing to consumers. Lighting efficiency improvements could come from single or multiple classes of technologies (e.g., incandescent, fluorescent, or LED).

5.11.2. Green Dream Scenario, Lighting

The Green Dream scenario calls for the elimination of the standard incandescent light bulb and assumes that all lighting products on the market will be as efficient as fluorescent lamps. Lighting products will be 70 percent more efficient than the average lighting product today. The improvements will again be the result of building standards for increased efficiency and an array of new more efficient lighting products that are both cost-effective and produce light that is pleasing to consumers. Lighting efficiency improvements could come from single or multiple classes of technologies (e.g., incandescent, fluorescent, or LED).

5.12. Space Heating

Although space heating consumes a substantial amount of electricity for those homes that use electric heating, electricity for space heating accounts for less than 4 percent of the residential electric load currently, due to the low saturation of electric heating, and is expected to account for even less of the residential electric load in 2050.

Current electric heating technology consists of resistance heating and heat pumps. Consumption is a function of the efficiency of the heating technology, heat loss of the dwelling, desired indoor temperatures, and local climate conditions. Resistance heating, the predominant electric heating technology in older homes, has not changed significantly over the past 35 years and likely will not be improved significantly by 2050. Heat pumps are found in most homes with electric heating built after 1983. They consume roughly 50 percent less energy than resistance heating in mild climates (savings are less in colder climates where electric resistance backup units are used at low outdoor temperatures).

Historic changes in the UEC for electric heating have been primarily a function of changes in building shell efficiency characteristics, changes in indoor temperature settings, and increases in heat pump saturation. Figure 5-10 presents the Energy Commission's average UECs for the period 1970 to 2016. The figure shows that the UECs dropped precipitously after the first oil shock in 1973. However, it is also possible that some of this drop is associated with measurement effort, since few if any studies of end-use consumption using statistical techniques such as conditional demand analysis were conducted prior to 1973. The Energy Commission data shows that the drop continued to the mid-1980s. By 1992 most major building efficiency standards were in place and the heating UECs for new buildings have remained constant since. The Energy Commission forecast shows no major improvements through 2016. The average UECs moved toward the marginal UECs as post-Title 24 houses became a larger share of the housing stock or, to a lesser extent, when older homes switched fuels or converted to heat pumps.

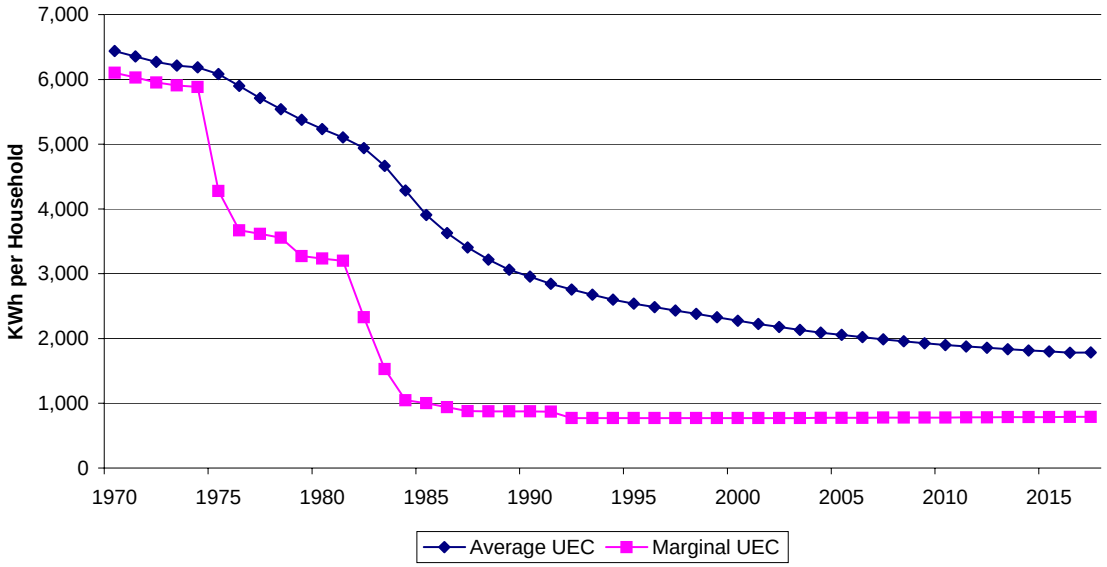


Figure 5-10: Electric heating average and marginal UECs

5.12.1. Optimistic Efficient Technology Scenario, Space Heating

In the OET scenario forecast for 2050, the research team assumed that general heating efficiency will likely improve through continued codes-based shell improvements. The average UEC will decline primarily from the introduction of new, more efficient housing to the overall housing stock and to a lesser extent through housing renovation. Marginal technology efficiency will likely remain about the same. There also will be a small increase in the percentage of homes using heat pumps to space heat.

The OET forecast assumes a 10 percent efficiency improvement, primarily due to shell improvements. The 10 percent efficiency improvement is applied to the average UEC for existing households and the marginal UEC for all new homes built between 2006 and 2050.

The total weighted average efficiency improvement by 2050 is approximately 20 percent to 30 percent, depending on the housing forecast.

5.12.2. Green Dream Scenario, Space Heating

The Green Dream scenario assumes that all existing buildings can be brought up to optimal insulation standards and all older homes with central electric heating systems convert to heat pump heating. The research team assumes that many homes that use electric room heaters will continue to use that technology. Under this scenario the team assumes that existing homes will be 30 percent more efficient, relative to the current average UEC.

New homes will have improved building shells and central electric heating systems will use more efficient heat pump technology. New homes will be 30 percent more efficient than the current marginal UEC.

The weighted average efficiency based on per-household consumption reduction relative to current per-household consumption is approximately 40 to 45 percent depending on the housing forecast.

5.13. Central Air Conditioning (CAC)

Air conditioning technology is primarily based on the transfer of heat via a fluid using compressors and condensers. As illustrated in Figure 5-11, decreases in CAC consumption have occurred over the past 25 years in response to both energy price shocks and energy efficiency standards. Utility programs have also assisted in the stimulating new higher efficiency CAC technologies; however, the majority of savings have occurred as a result of standards. While further increases in the efficiency of CAC technology are expected, significant efficiency gains will be captured in the latest appliance standards as of 2006, which require SEER 13 units. The greatest energy-saving opportunities between the present and 2050 will come from better sizing of CAC systems, more efficient duct design, better controls, reduction of solar gains through insolation-blocking window glazing, cool roofs and trees, and potentially through the use of some form of evaporate cooling technology, especially in hot dry regions. While there may be some additional air conditioning technology efficiency gains using traditional technology, they will not likely be as large as the most recent improvements required by standards. Housing size increases will offset some of the efficiency gains.

Solid-state cooling technology presents an alternative to the traditional compressor-based technology (ACEEE 2004). At this time, solid-state cooling appears to be less efficient than mechanical cooling technology, though there are indications that efficiency will improve significantly. Currently the applications using solid-state cooling technology are minimal as compared to the thermal requirements of space conditioning. It is unlikely that solid-state cooling will be able to replace mechanical cooling for large space conditioning applications (Bourne, pers. comm. 2006).

Figure 5-11 shows the Energy Commission's marginal and average UEC changes over time. The step down pattern shown in the marginal UEC is due to increasingly stringent state and federal appliance and building standards. The average UEC lags the marginal UEC reflecting the time required for equipment replacement as a normal part of equipment lifecycle.

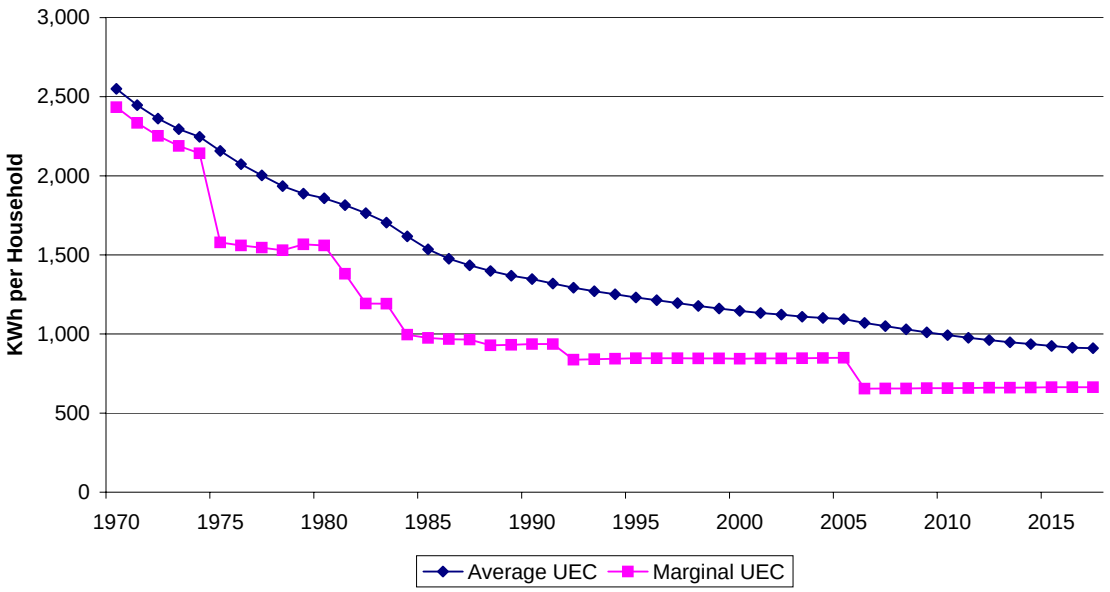


Figure 5-11: Central air conditioning average and marginal UECs weighted average for all households with technology

5.13.1. Optimistic Efficient Technology Scenario, CAC

The OET forecast assumes both improvements in air conditioning technology and improvements in building shell efficiency. It also assumes that existing household air conditioning will be 20 percent more efficient than the current marginal UEC through existing housing renovation and the implementation of more efficient air conditioning units (including proper air conditioner installation and maintenance practices) by 2050.

New houses built between 2006 and 2050 will require night cooling technology and insolation blocking on all windows. It is assumed that new household air conditioning will be 35 percent more efficient than the current marginal UEC.

Excluding increased utilization, it is assumed that the weighted average household consumption reduction relative to current household consumption would be approximately 50 percent under this scenario. Because CAC UECs are already fairly low in California, these improvements may not be cost effective based on current valuation of supply-side avoided cost benefits.

5.13.2. Green Dream Scenario, CAC

The Green Dream scenario assumes that all existing buildings with CAC will have their cooling load reduced though a combination of the following: increased insulation, major reductions in solar gains though windows, retrofit passive cooling measures, evaporative cooling measure, and shading. In addition, technology standards would force higher efficiency CAC units and regulation would require more appropriate sizing of CAC units. Through these measures, cooling load for existing buildings could be reduced 40 percent relative to the 2006 marginal UECs.

Under the Green Dream scenario, new buildings will employ passive cooling technologies to the greatest degree possible in addition to other measures including evaporative cooling technology. Future new buildings could be 70 percent more efficient than existing new buildings.

Excluding increased utilization, it is assumed that the weighted average household consumption reduction relative to current household consumption would be approximately 70 percent under this scenario.

Again, because central air conditioner UECs are already fairly low in California, these improvements may not be cost effective based on current valuation of supply-side avoided cost benefits.

5.14. Room Air Conditioners (RAC)

Room air conditioners account for less than 1 percent of residential electricity use in California. Efficiency levels, as measured by EER, have improved over time in response to standards. From 1990 to 2004, Energy Commission data indicates that the UEC dropped about 6 percent for both single-family and multifamily room air conditioners, as seen in Figure 5-12. Further improvements in RAC efficiency are likely; however, the cost effectiveness of these improvements may be limited by the relatively low UEC.

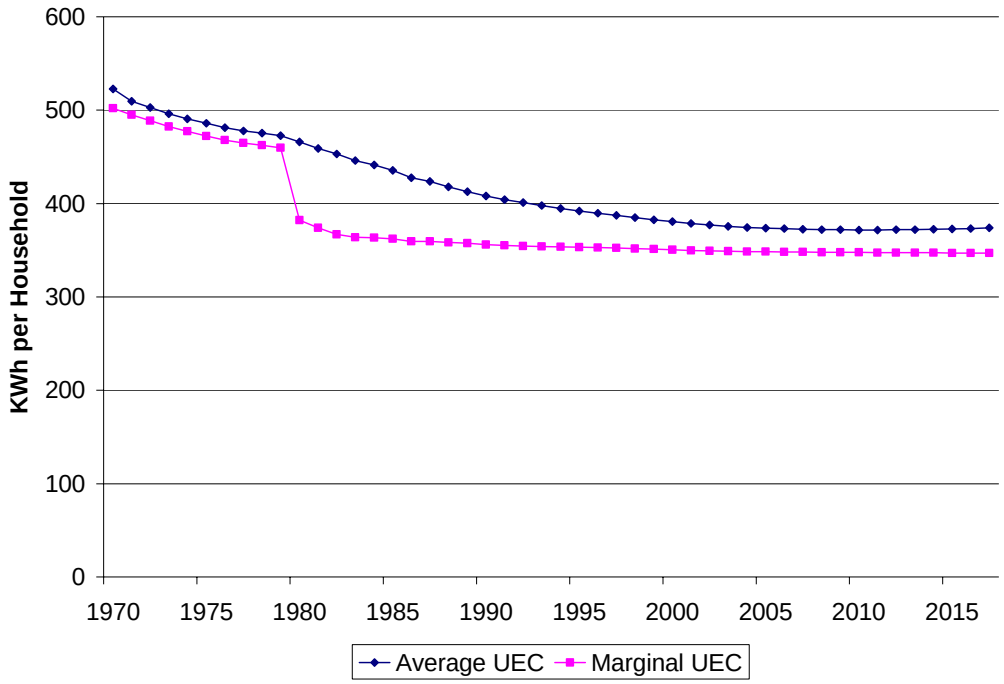


Figure 5-12: Room air conditioning average and marginal UECs weighted average for all households with technology

5.14.1. Optimistic Efficient Technology Scenario, Room AC

The OET scenario assumes more rigorous standards for room air conditioners in the future, yielding an average 10 percent efficiency improvement relative to the marginal 2006 UEC.

5.14.2. Green Dream Scenario, Room AC

The Green Dream scenario assumes more rigorous standards being applied to room air conditioners in the future, yielding an average 30 percent efficiency improvement relative to the marginal 2006 UEC.

5.15. Furnace Fan

Furnace fans represent roughly 2 percent of residential electric use in California. Energy Commission data indicate that the furnace fan UEC for gas space heating has not changed since 1970 and is not expected to change by 2016.

5.15.1. Optimistic Efficient Technology Scenario, Furnace Fan

The OET scenario assumes more rigorous standards for furnace fans in the future. Higher efficiency motors would be specified and improvements in duct design would be made, yielding an average 10 percent efficiency improvement relative to the current marginal UECs.

5.15.2. Green Dream Scenario, Furnace Fan

The Green Dream scenario assumes high-efficiency motors, duct leakage abatement, and reduced heating requirements yielding an average 20 percent efficiency improvement relative to the current marginal UECs.

5.16. Summary of UEC Trajectories to 2050 under OET Scenario

Figures 5-13 through 5-24 summarize the UECs for each end use discussed above for the OET scenario. The first few charts present results for the non-space conditioning end uses. UECs for space conditioning end uses are presented subsequently by climate zone and building type. As noted previously, UECs from 1970 to 2004 are historic Energy Commission estimates and UECs from 2005 to 2016 are Energy Commission forecast values. UECs from 2017 to 2050 are the authors' forecasts for the OET scenario.

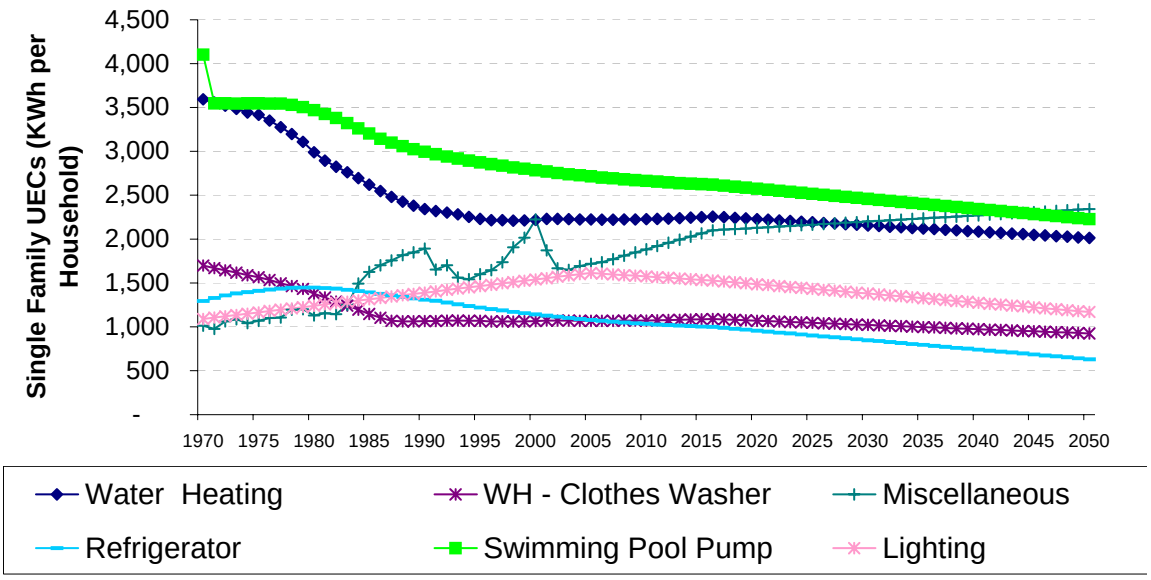


Figure 5-13: Single-family non-space conditioning UECs, OET scenario part 1

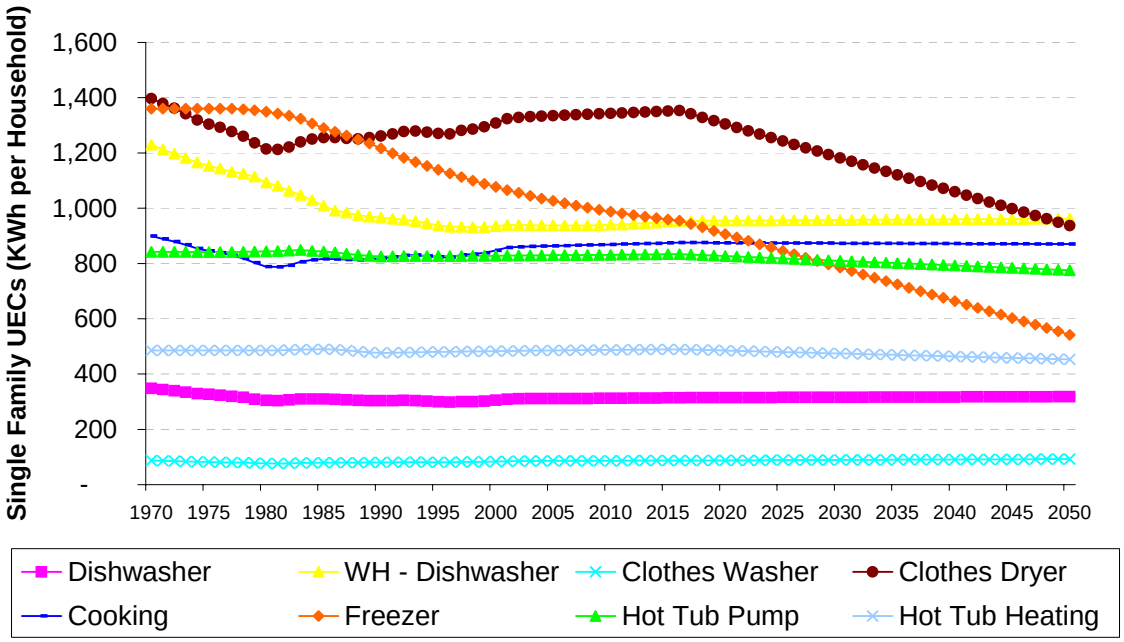


Figure 5-14: Single-family non-space conditioning UECs, OET scenario part 2

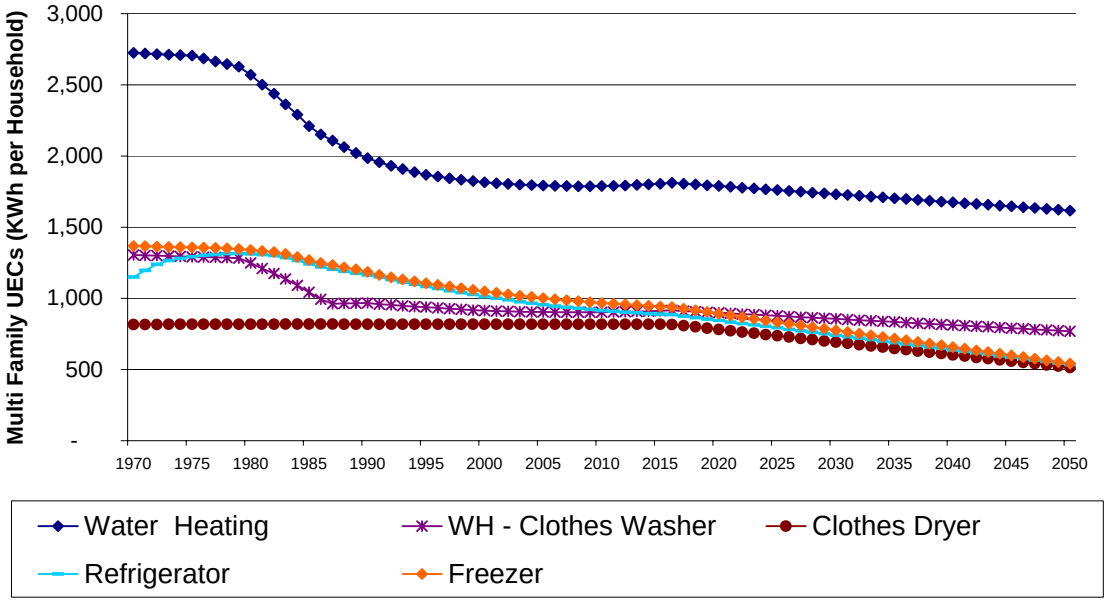


Figure 5-15: Multifamily non-space conditioning UECs part 1, OET scenario

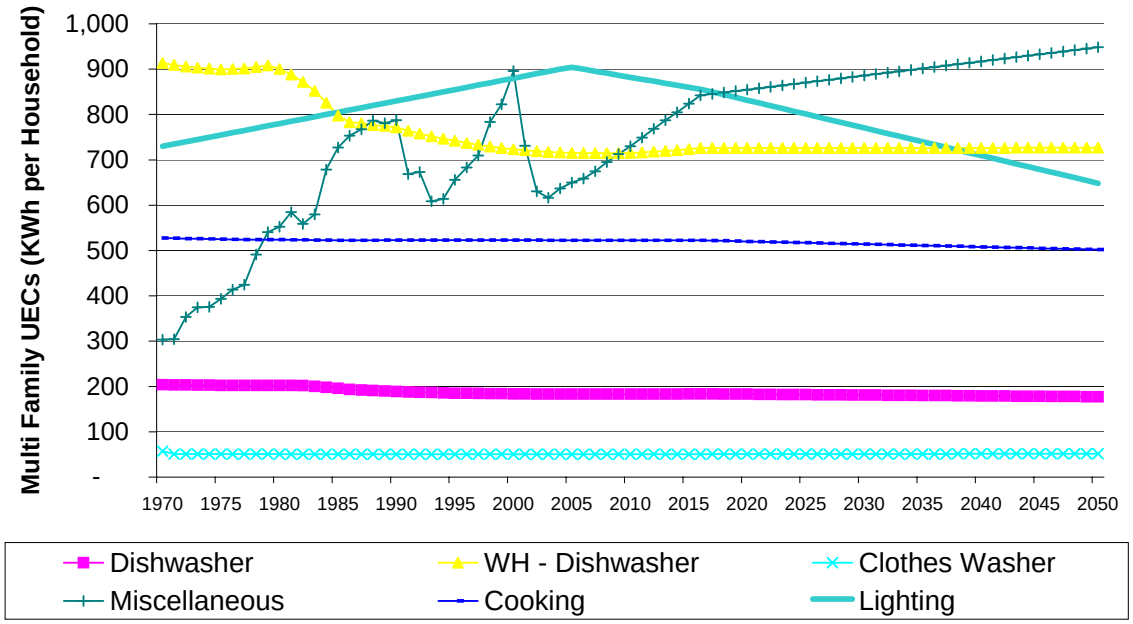


Figure 5-16: Multifamily non-space conditioning UECs part 2, OET scenario

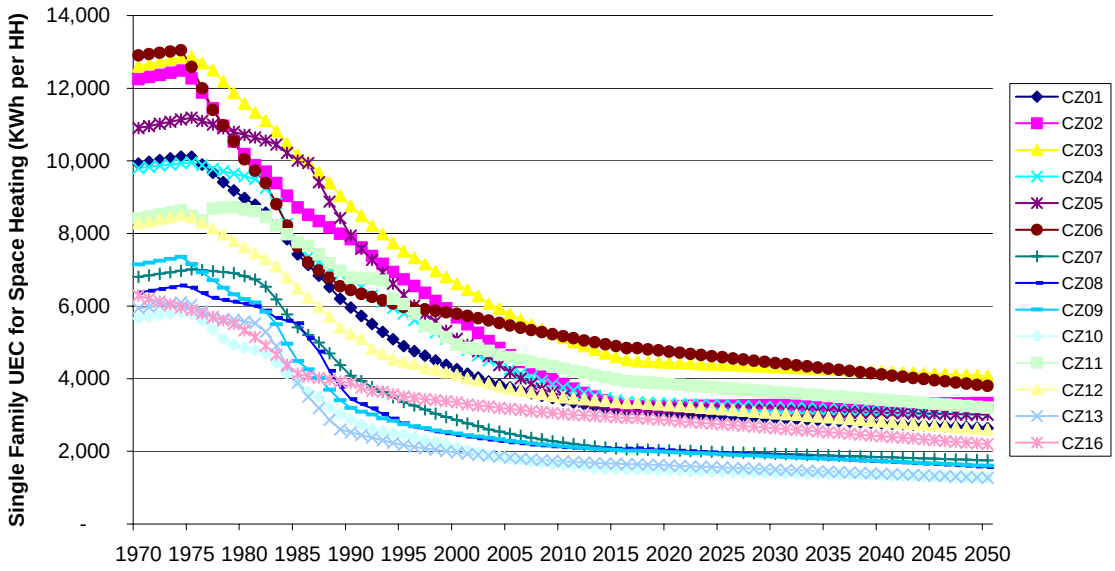


Figure 5-17: Single-family space heating UEC historic and OET forecast by climate zone

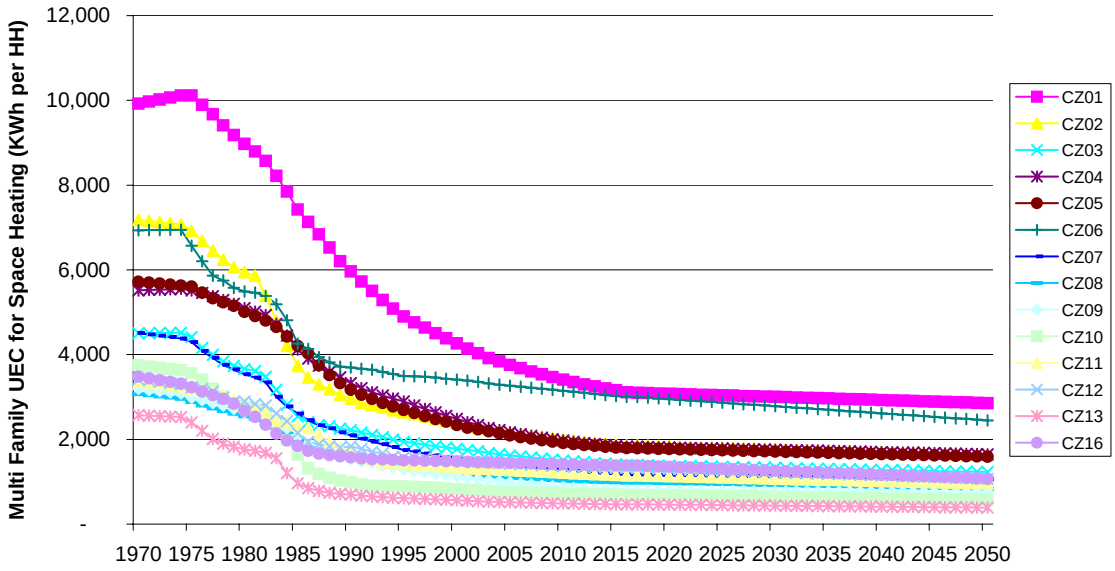


Figure 5-18: Multifamily space heating UEC historic and OET forecast by climate zone

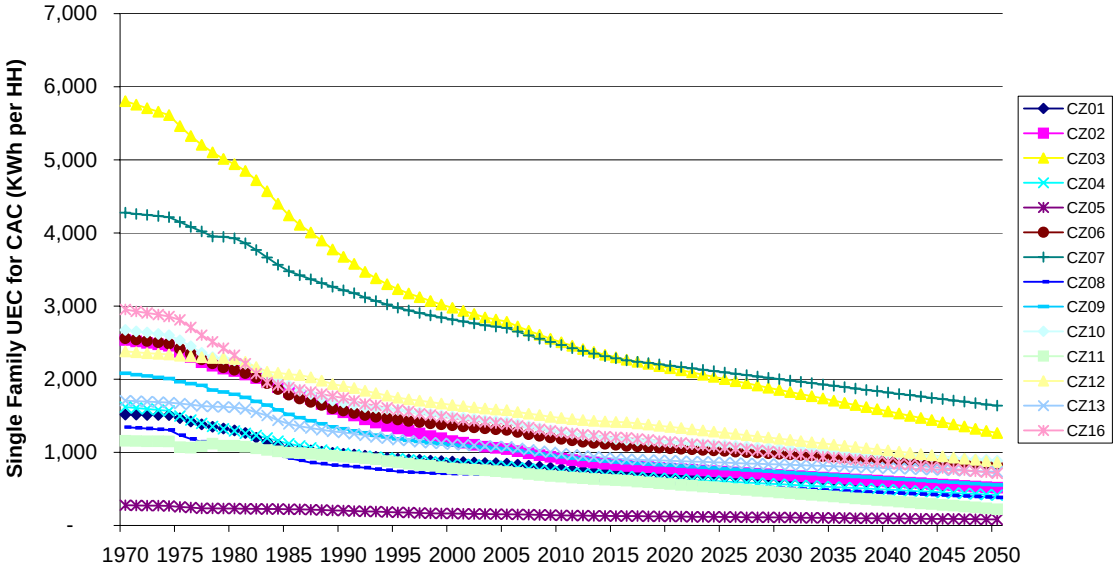


Figure 5-19: Single-family CAC UEC historic and forecast by climate zone

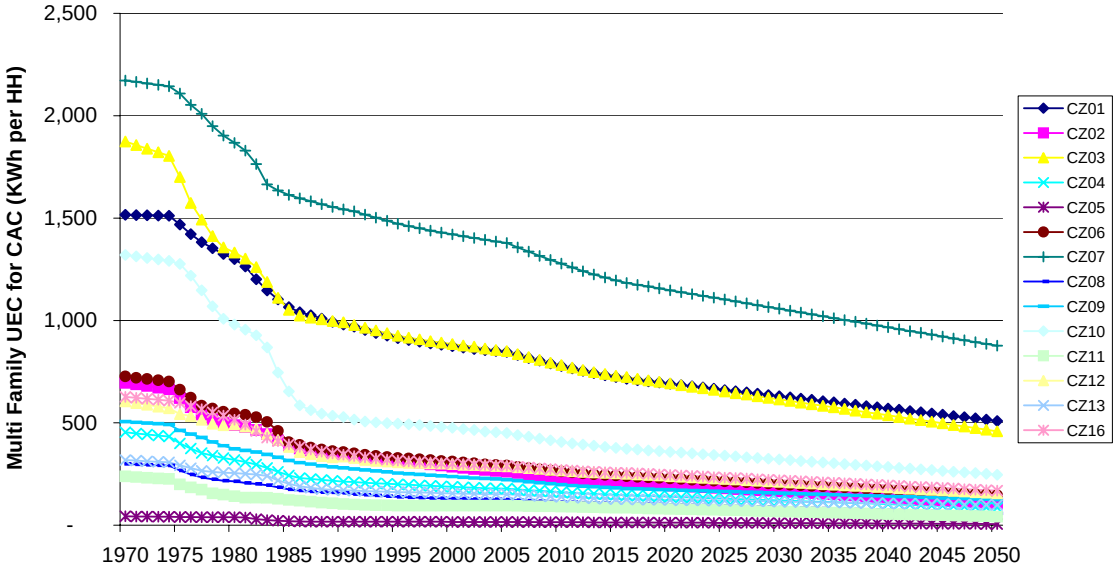


Figure 5-20: Multi-family CAC UEC historic and forecast by climate zone

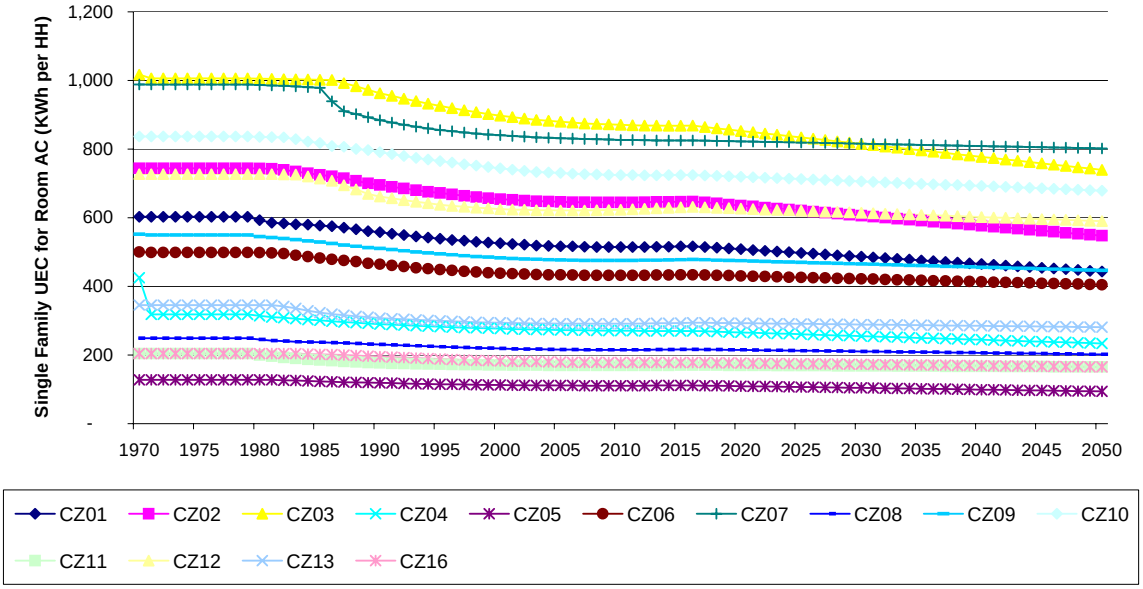


Figure 5-21: Single-family room air conditioner UEC historic and forecast by climate zone

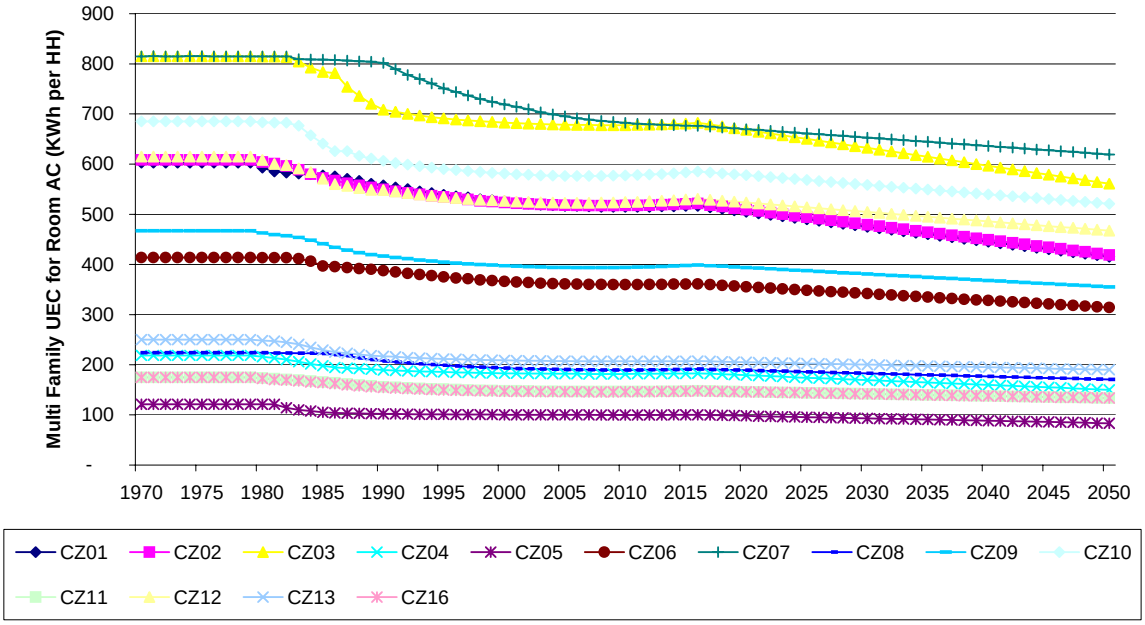


Figure 5-22: Multifamily room air conditioner UEC historic and forecast by climate zone

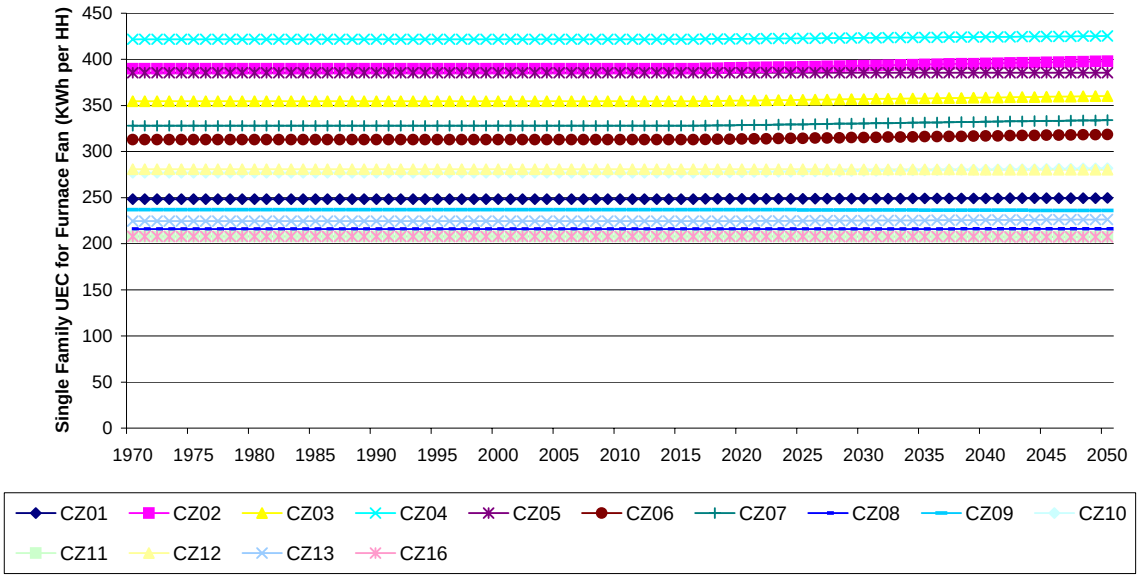


Figure 5-23: Historic and forecast single-family furnace fan UEC by climate zone

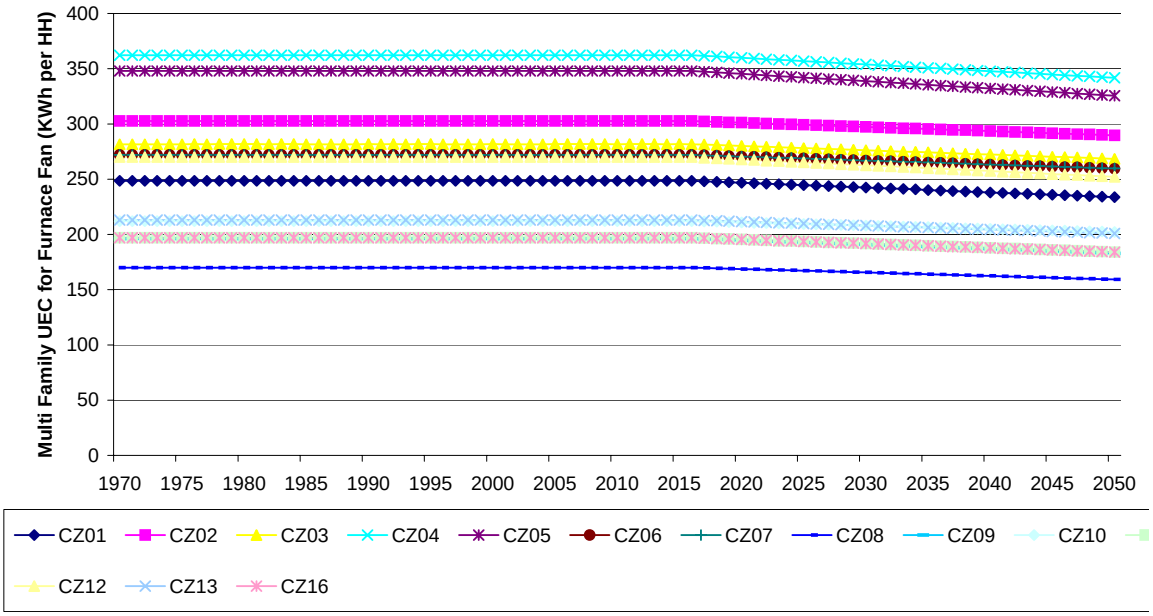


Figure 5-24: Historic and forecast multifamily furnace fan UEC by climate zone

5.17. End-Use Saturation Forecast

This section presents the research team's assumed electric saturation levels by end use. These saturation estimates are part of this study's saturation forecast, defined as *Baseline Continued Diffusion,* in Section 4. Note that the alternate scenario, defined as the *Static Saturation Benchmark*, assumes that electric saturations are frozen at current levels.

In Figure 5-25 through 5-32, the saturation percentages shown from 1970 to 2004 are historic estimates made by the Energy Commission. Saturation percentages from 2004 to 2016 are those forecasted by the Energy Commission. Saturation levels for 2050 are the research team's estimates. Saturation percentages beyond 2016 are linearly derived for each year between the Energy Commission forecast for 2016 and the scenario estimate for 2050.

Historic data show that rates of growth for the adoption of end-uses by households slow over time as the end-use matures. Technology diffusion theory (Rogers 2003) and historical evidence show that the saturation of a new product is slow at first, increases with wider acceptance, and then slows again to reach an asymptotic level. To capture the declining rate of change the research team assumed that the percent change for the 34 years between 2016 and 2050 will be the same as the percent change for the 12 years between 2004 and 2016, with a few exceptions. The CAC saturation was capped at 80 percent, single-family dishwasher saturation was capped at 80 percent and multifamily dishwasher saturation was capped at 70 percent.

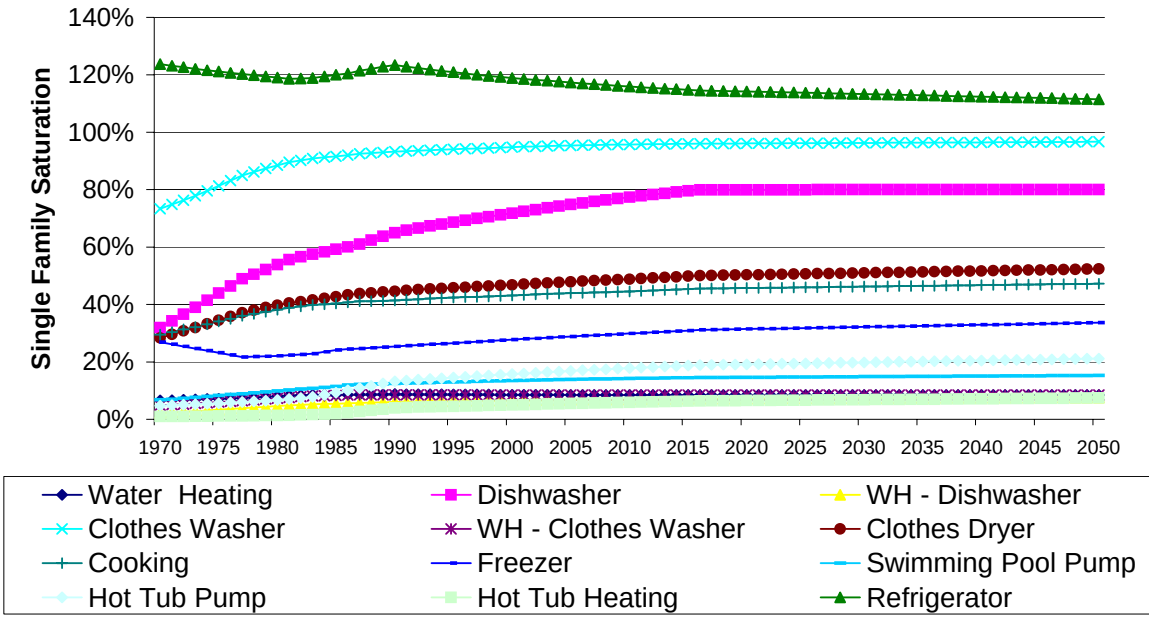


Figure 5-25: Saturations of non-climate-dependent single-family end uses, historic and forecast

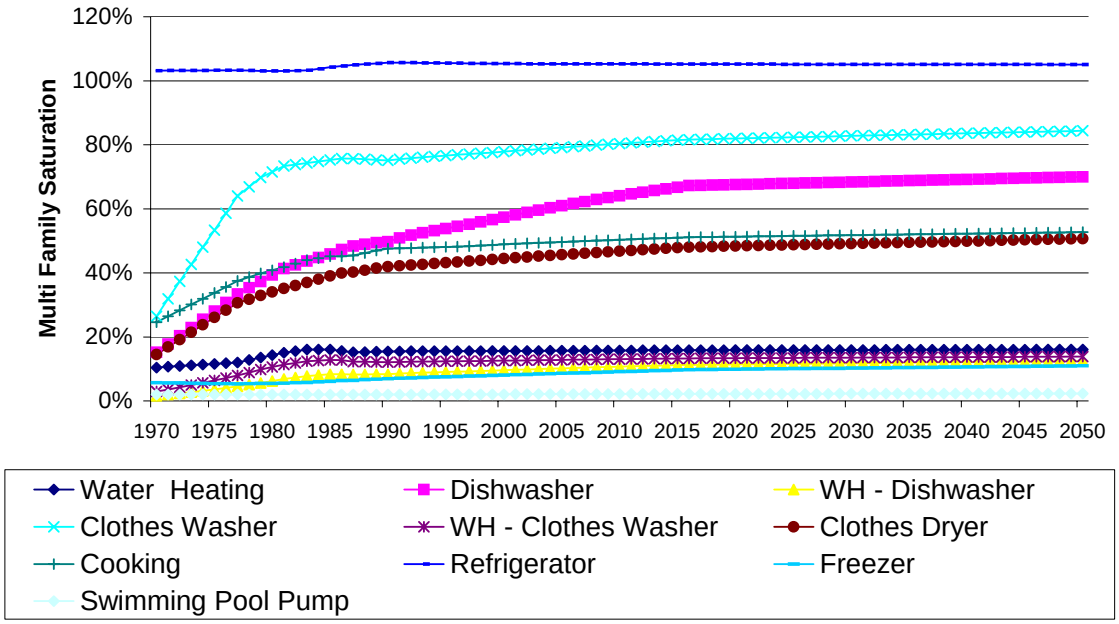


Figure 5-26: Saturations of non-climate-dependent multifamily end uses, historic and forecast

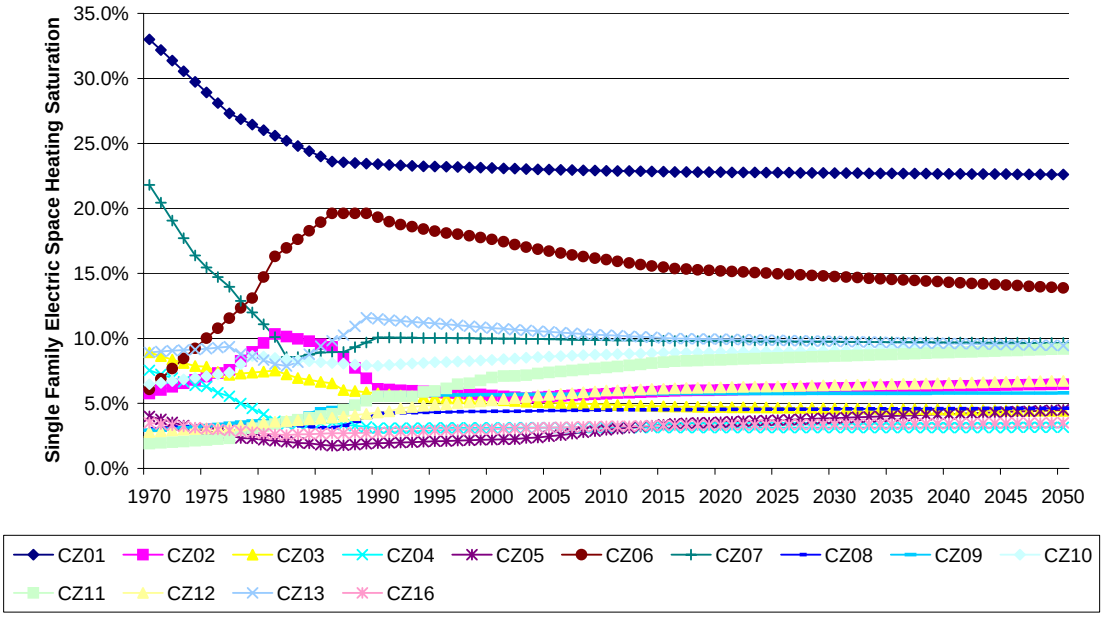


Figure 5-27: Saturations of electric space heating for single-family households, historic and forecast by climate zone

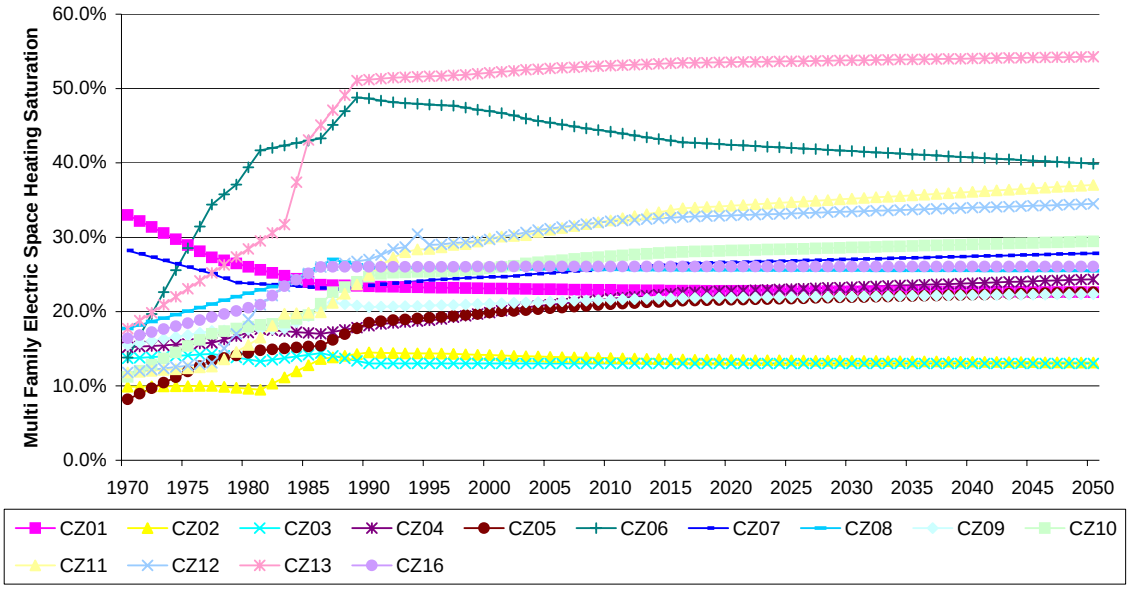


Figure 5-28: Saturations of electric space heating for multifamily households historic and forecast by climate zone

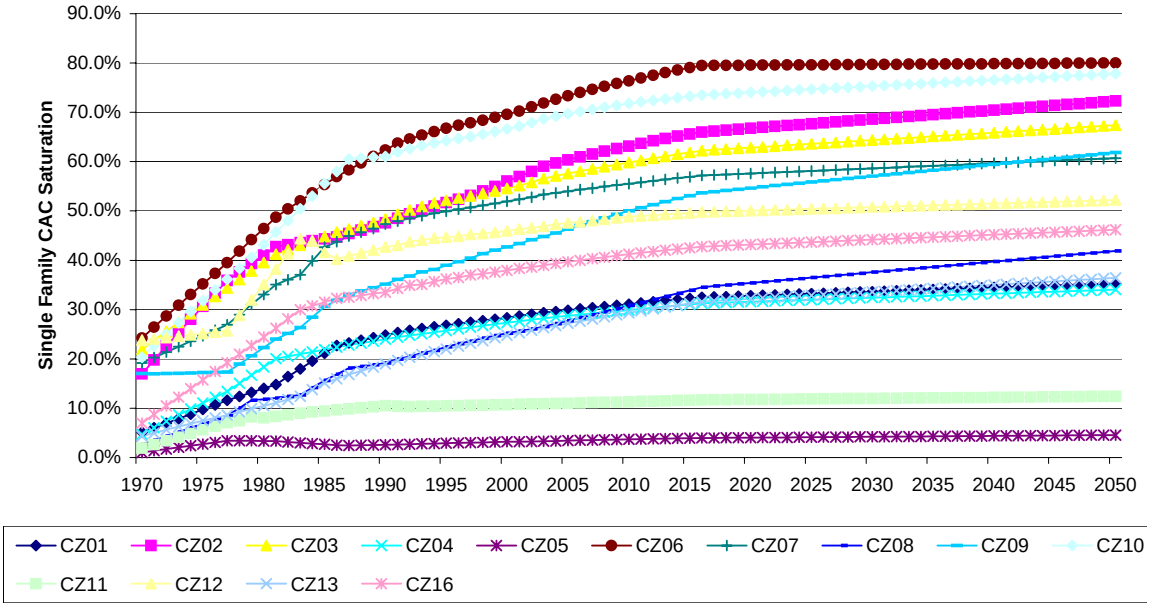


Figure 5-29: Saturations of central air conditioning for single-family households, historic and forecast by climate zone

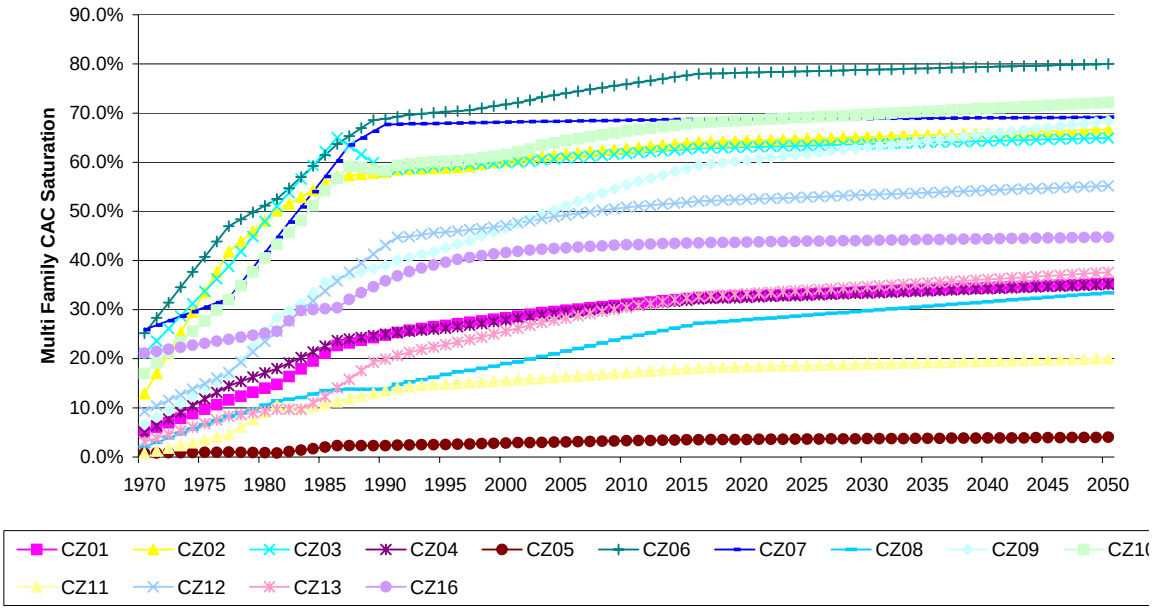


Figure 5-30: Saturations of central air conditioning for multifamily households, historic and forecast by climate zone

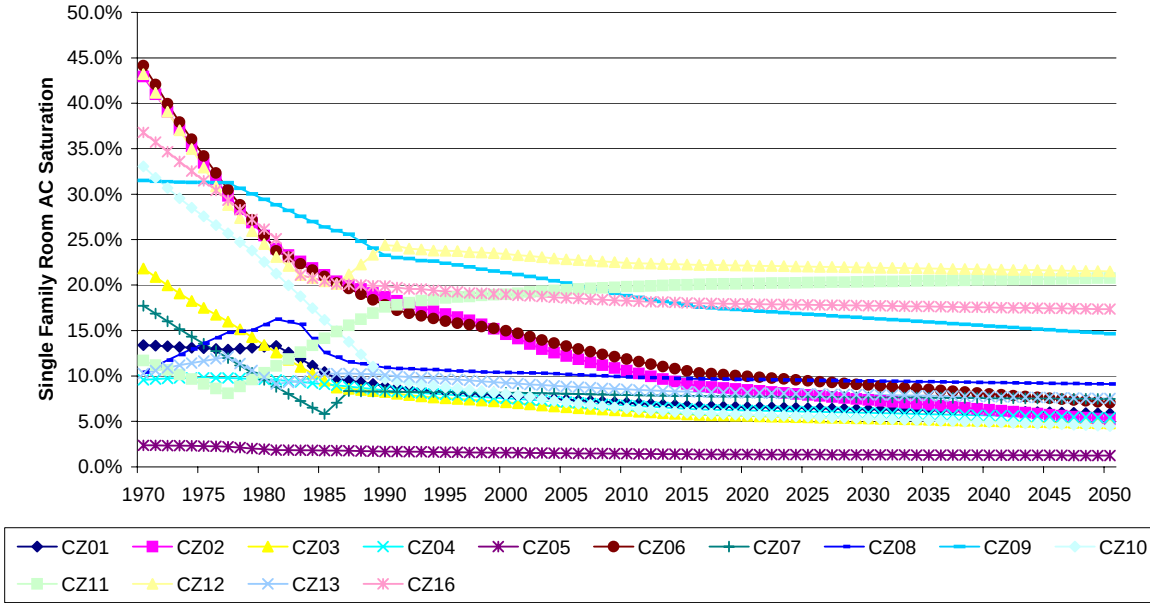


Figure 5-31: Saturations of room air conditioners for single-family households, historic and forecast by climate zone

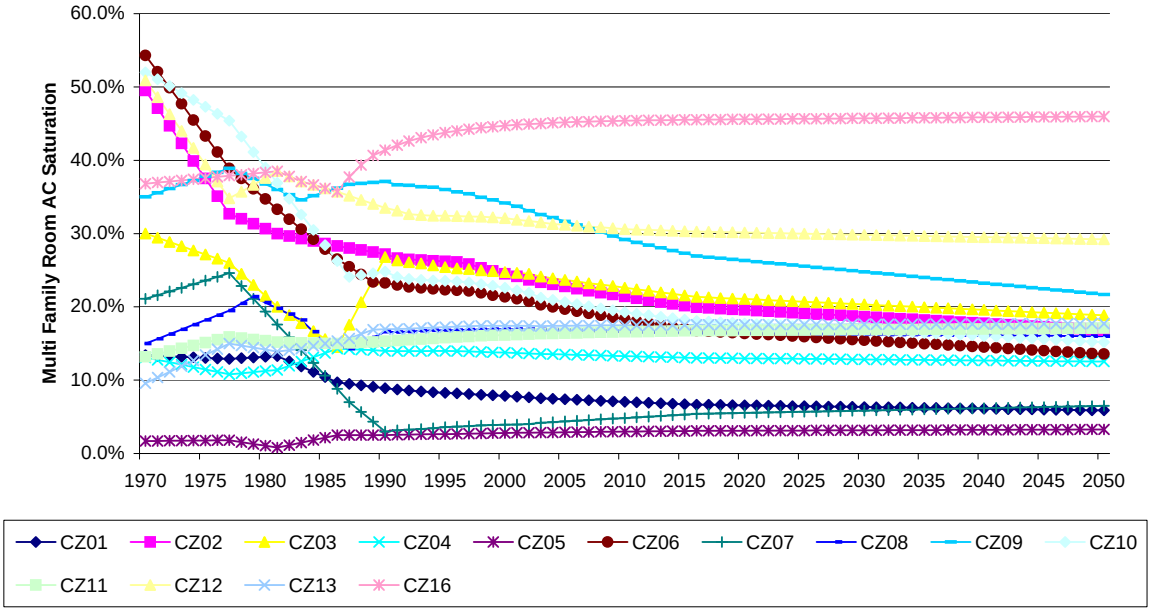


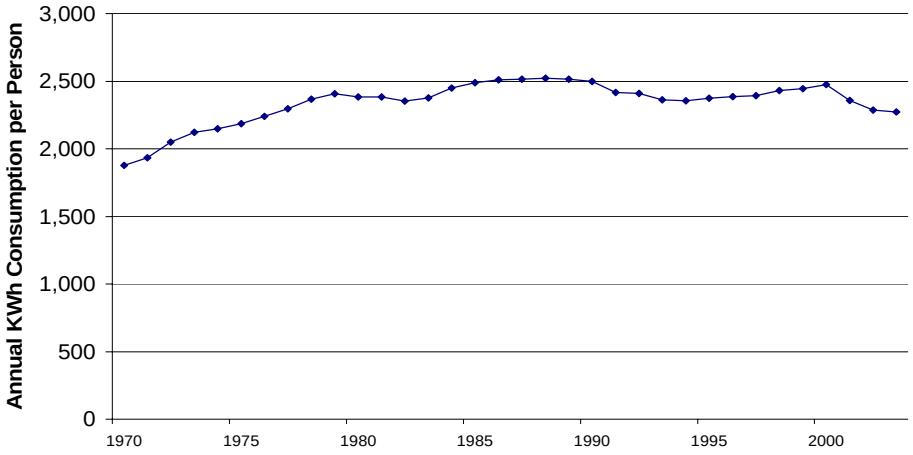
Figure 5-32: Saturations of room air conditioners for multifamily households, historic and forecast by climate zone

6.0 Summary of Observations from Retrospective Analysis

In preparation for developing the study scenario forecasts, the research team extensively reviewed and analyzed the Energy Commission's data on California's electric end-use holdings and its UECs for the period 1970 to 2004. In addition, key electricity consumption drivers such as population were analyzed for longer periods using additional sources. In the course of this analysis the following historic trends were observed:

- As shown in Figure 3-1 and Figure 6-1, despite maintaining relatively flat, per capita aggregate end-use consumption has continually increased. For many end-uses, this aggregate growth has been driven by the combination of population growth and increasing end-use saturation levels. Major electric saturation growth areas included central air conditioning, clothes dryers, and dishwashers.
- Adoption of an increasing array of electronic products contributed strongly to increases in household electricity consumption.
- New home sizes increased at the rate of 25 square feet per year for single-family dwellings (NAHB 2005) and five square feet per year for multifamily dwellings (U.S. Census Bureau 2006b).
- There is recent evidence that energy service demands for illumination continue to increase (RLW 2005 and Siminovitch, pers. comm. 2005).
- As shown in Table 6-1, a significant portion of California's maintenance of fairly constant per capita electric energy consumption between 1985 and 2000 was the result of per capita reductions for refrigerators, space heating, and water heating, with refrigerators making up the major of reduction. The roughly 200 kWh per capita reduction over this period was offset by a roughly equivalent increase associated with the "Miscellaneous" and "Lighting" end uses.
- Major efficiency improvements have been achieved in many but not all end uses. End uses associated with major efficiency improvements over the past 25 years include refrigeration and space conditioning. Those with more negligible improvements include clothes dryers, clothes washer motors, and furnace fans. Several end uses such as hot water associated with clothes washing, dish washing, and lighting are now in transition to higher efficiency levels.
- The existing literature on the effect of price on end-use efficiency improvements is inadequate. Existing long-term electricity elasticity values tend to be driven by fuel substitution impacts and are confounded by the temporal correlation between price increases and policy interventions for the period during and following the energy crises of the 1970s. The research team knows of no residential elasticity studies that can provide reliable end-use values for California exclusive of fuel substitution effects. It appears that consumers do not permanently change their usage of many major electric appliances (e.g., refrigerators and home electronics) due to increases in electricity prices.
- Instead, there is stronger evidence that most of California's significant increases in end-use efficiency levels were driven by the combination of state and federal appliance and building standards and energy efficiency programs (Bernstein et al. 2002). In a few cases, notably electronics, efficiency improvements have occurred as a

by-product of other product performance objectives, for example, the need to reduce heat which would otherwise shorten product life.



Source: CEC 2005b

Figure 6-1: California per capita residential electricity consumption, 1970 to 2004

Table 6-1: Changes in per capita residential electricity consumption (kWh/person)

End Use	2000 Versus 1970	2000 Versus 1985
Water Heating	16	-25
Water Heating - Dishwasher	33	7
Clothes Washer	6	1
Clothes Dryer	78	14
Other	345	133
Cooking	38	5
Refrigerator	-58	-123
Freezer	-14	-5
Pool/Spa	49	12
Lighting	126	40
Space Heat	-73	-58
Fan for Gas Furnace	1	-2
Central Air Conditioning	64	-6
Room Air Conditioning	-14	-5
Total	598	-12

Source: CEC 2005b through i.

7.0 Scenario Analysis Results

The primary objectives of this project were to develop a method to analyze long-term residential energy consumption under alternative futures for California and to develop initial estimates of possible electricity consumption levels for the residential sector by 2050. An end-use level modeling framework was developed that uses transparent assumptions that can be easily modified to test the effects of alternative assumptions on population, housing density, energy service levels, and end-use efficiency potentials.

This section presents model results for each of the key scenarios developed in this initial effort. The scenarios are defined in Section 4 and underlying end-use efficiency assumptions are provided in Section 5. General policy implications are discussed after presentation of the scenario results.

7.1. Scenario Results

Tables 7-1 and 7-2 and Figures 7-1 and 7-2 present the aggregate and per capita results for this study's scenario analyses. Unless otherwise specified, the scenario results presented are all based on the Baseline Continued Saturation Diffusion saturation assumptions shown at the end of Section 5. Under the Frozen Efficiency scenario using the CADOF population forecast, electricity consumption increases from roughly 83 TWh today to approximately 133 TWh by 2050 (a roughly 60 percent increase) and basically equal to the forecasted growth in population. Under the Frozen Efficiency scenario using the Landis population forecast, electricity consumption increased to over 160 TWh by 2050—almost double current consumption. In both cases, most of the increase in aggregate consumption is driven by California's growing population and per-household growth in the "Miscellaneous" end use. Note that the rate of growth under Frozen Efficiency is less than the growth that occurred from 1970 to 2005. This is because efficiency levels are frozen on the margin at levels tied to the latest California and federal standards, which require efficiencies significantly above current stock averages. Consequently, per capita consumption remains flat under the Frozen Efficiency scenario. As was the case for the period 1985 to 2000, per capita consumption remains flat due to the roughly equivalent canceling of efficiency gains and increases in service demands.

To assess the effect of continued changes in electric saturation, the research team replaced the saturation forecasts in the Baseline Continued Saturation Diffusion saturation scenario with saturation values frozen at today's level, as defined by the Static Saturation Benchmark. Comparison of these two scenario results indicates that continued increases in electric saturation of traditional end uses are forecasted to level off and account for only 3 percent of the increase in consumption (using the CADOF population forecast).

Under the OET scenario, combined with the CADOF population forecast, consumption is forecasted to increase to 116 TWh—roughly 16 percent less than under the Frozen Efficiency scenario, but still 40 percent more than today's level. Consumption under the Green Dream scenario is forecasted to decline, after a rise from 2005 to 2016, to 84 TWh—or 37 percent less than under Frozen Efficiency. Much of the savings in both of these scenarios is associated with improvements in the refrigeration, central air conditioning, and lighting end uses. Considering the significant improvements in the first two end uses over the past 25 years, the study's forecasts of continued improvements should be considered aggressive,

especially in the case of the Green Dream scenario. Other end uses such as water heating, electric space heating, clothes drying, and ventilation systems contribute less to overall reductions in consumption because they have either smaller relative savings potential, are end uses with low electric saturation, or have low baseline UECs. Despite aggressive efficiency potential assumptions in the Green Dream scenario, population increases and growing miscellaneous consumption keep aggregate consumption from dropping below current levels.

Per capita residential electricity use decreases by 9 percent and 33 percent from today's levels under the OET and Green Dream scenarios, respectively. From this perspective, the Green Dream scenario would represent a dramatic increase in efficiency that goes well beyond California's historic rate of efficiency improvement. The annual rate of decrease in per-capita consumption associated with these scenarios is 0.3 percent and 1 percent for the OET and Green Dream scenarios, respectively.

As a result of the Kyoto Protocols, the year 1990 is benchmark commonly used to set GHG emission reduction targets. Although GHG emissions strategies are likely to use a combination of approaches, including demand side, supply side, offsets, and sequestration, it is useful to assess the extent to which energy efficiency alone could reduce consumption relative to 1990 levels. Forecasted consumption in 2050 under the Frozen Efficiency, OET, and Green Dream scenarios is 79 percent, 54 percent, and 12 percent higher, respectively, than consumption in 1990.

An additional scenario that was explored for this analysis is the Higher Density housing scenario, which is defined in Section 4. This is a very aggressive scenario in which the ratio of multifamily to single-family residences is dramatically shifted over the next 45 years. The only combination of scenarios tested, excluding the PV scenario discussed below, that reduces electric energy consumption to below 1990 levels combines the CADOF population forecast, the Green Dream efficiency levels, and the extremely aggressive Higher Density housing scenario.

Table 7-1: Residential electricity consumption in California aggregate, per household and per capita forecasts

Forecast Scenarios for 2050	GWh	kWh per Household	kWh per Capita
Frozen Eff. w/ Landis et al. pop. forecast	160,718	7,263	2,402
Frozen Eff. w/ CADOF pop. forecast	133,192	7,313	2,432
Optimistic Eff. Tech w/ CADOF pop. forecast	114,786	6,303	2,095
Green Dream w/ CADOF pop. forecast	83,627	4,592	1,527
Green Dream w/ CADOF pop. forecast/higher density	67,710	3,718	1,236
Historic Values			
Consumption in 1990	74,528	7,232	2,499
Consumption in 2004	83,265	6,983	2,276

Table 7-2: Changes in residential electricity consumption scenarios relative to 1990 and 2004

Scenario	Percent Change	GWh (%)	kWh per Household (%)	kWh per Capita (%)
Frozen Efficiency	From Consumption in 1990	179	101	97
	From Consumption in 2004	160	105	107
OET	From Consumption in 1990	154	87	84
	From Consumption in 2004	138	90	92
Green Dream	From Consumption in 1990	112	63	61
	From Consumption in 2004	100	66	67

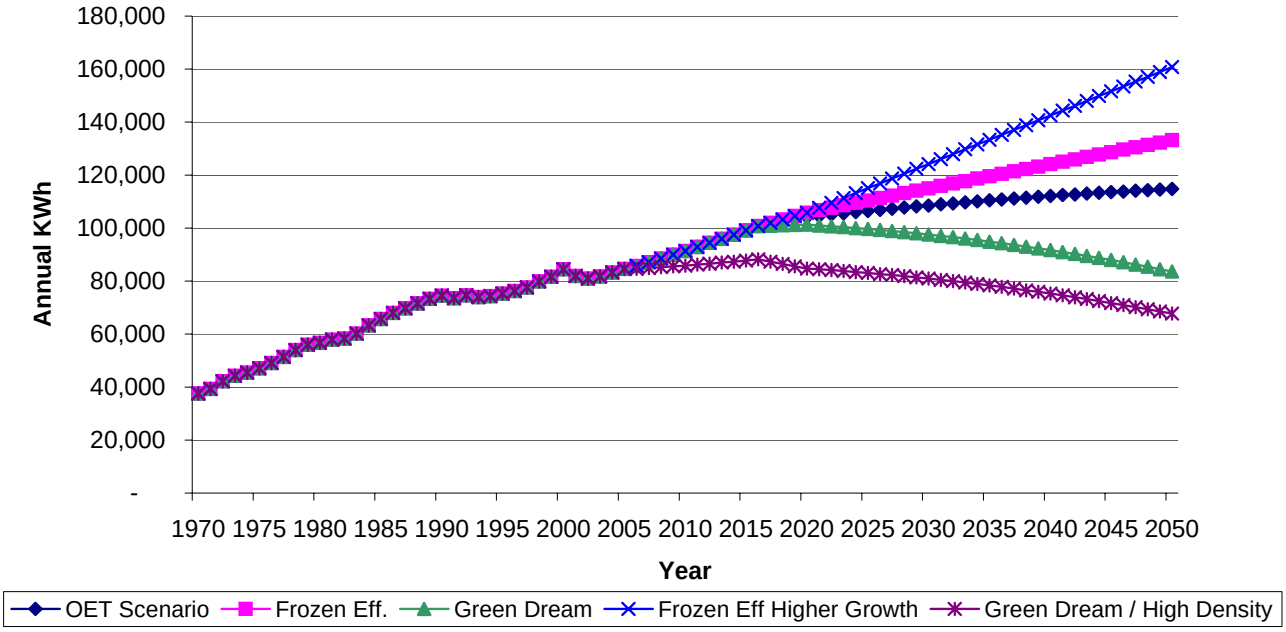


Figure 7-1: California residential electricity consumption to 2050 under efficiency scenarios

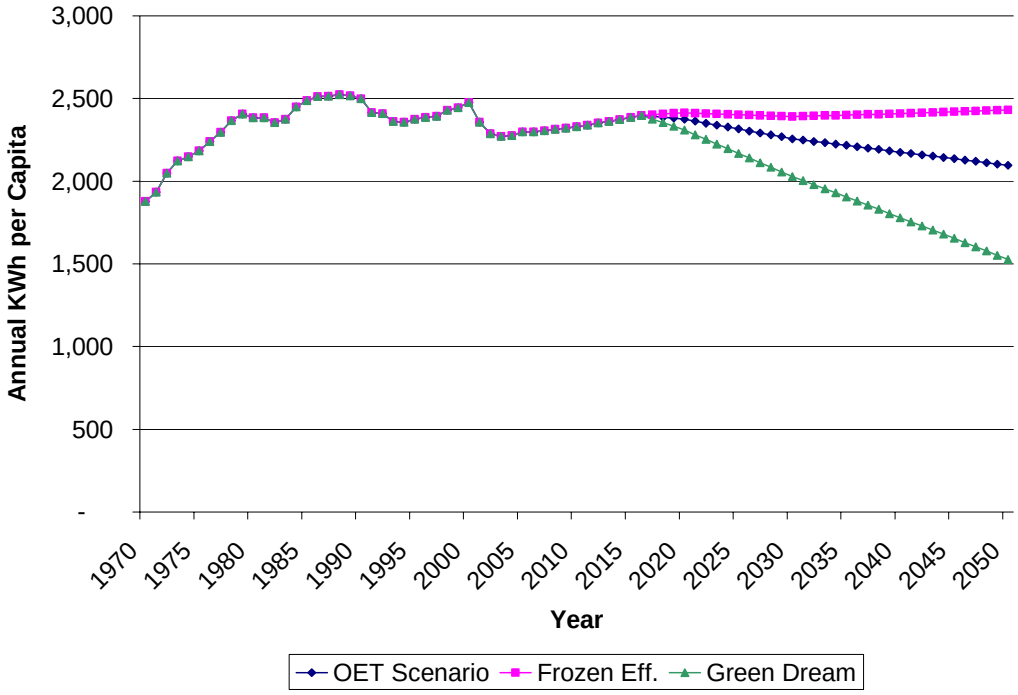


Figure 7-2: Resulting residential kWh per capita under efficiency scenarios

7.2. Scenario Results with End-Use Detail

Tables 7-3 through 7-7 provide additional end-use results for each of the scenarios. The tables also show the average efficiency change between 2006 and 2050. Combining the average efficiency adjustment and energy service change produces the change in the average UEC between 2006 and 2050. Table 7-3 and Table 7-4 present end-use results for the Frozen Efficiency scenarios under the Landis and CADOF population growth estimates, respectively. Tables 7-5 through 7-7 provide end-use results for the OET, Green Dream, and Green Dream plus Higher Density scenarios. Finally, the tables show annual energy consumption by end use. Figure 7-3 through Figure 7-8 present the end-use consumption trends over the entire analysis period (1970 to 2050) under the OET scenario.

Table 7-3: Residential end-use energy consumption forecasting model results for 2050

Residential Energy Requirement	**160,718 GWh**
California Population in 2050	**66,906,185**
Scenario	
UEC =	**Frozen Efficiency**
Saturation =	**Continued Trend**
Population =	**Landis, Urban Growth Study**
Density =	**Baseline**

	Average Efficiency Adjustment From 2006 (%)		Average UEC in 2050 (kWh/ Household/ Year)		Electric Energy in 2050 (GWh per Year)	
End Use	**Single Family**	**Multi-family**	**Single Family**	**Multi-family**	**Single Family**	**Multi-family**
Water Heating	93	96	2,118	1,702	2,803	1,786
Dishwasher	96	97	318	177	3,967	812
Water Heating - Dishwasher	100	100	1,013	765	1,197	622
Clothes Washer	97	97	88	49	1,325	271
Water Heating - Clothes Washer	100	100	1,156	962	1,522	870
Clothes Dryer	95	95	1,338	735	10,932	2,433
Miscellaneous	100	100	2,603	1,054	40,584	6,892
Cooking	95	96	870	502	6,411	1,730
Refrigerator	67	67	788	669	13,705	4,597
Freezer	67	68	678	677	3,555	1,775
Swimming Pool Pump	93	97	2,475	3,438	5,885	517
Hot Tub Pump	97	NA	816	NA	2,691	NA
Hot Tub Heating	96	NA	477	NA	553	NA
Lighting	80	80	1,413	756	22,033	4,943
Space Heating	71	79	2,948	1,385	2,688	2,037
Furnace Fan	100	100	378	319	2,340	490
Central Air Conditioning	62	61	1,160	354	7,431	500
Room Air Conditioning	92	94	561	410	499	322

Table 7-4: Residential end-use energy consumption forecasting model results for 2050

Residential Energy Requirement	**133,192 GWh**
California Population in 2050	**54,777,700**
Scenario	
UEC =	**Frozen Efficiency**
Saturation =	**Continued Trend**
Population =	**CADOF (1/16/06)**
Density =	**Baseline**

	Average Efficiency Adjustment From 2006 (%)		Average UEC in 2050 (kWh/ Household/ Year)		Electric Energy in 2050 (GWh per Year)	
End Use	**Single Family**	**Multi-family**	**Single Family**	**Multi-family**	**Single Family**	**Multi-family**
Water Heating	93	96	2,118	1,702	2,318	1,454
Dishwasher	96	97	318	177	3,279	661
Water Heating - Dishwasher	100	100	1,013	765	990	506
Clothes Washer	97	97	88	49	1,096	221
Water Heating - Clothes Washer	100	100	1,156	962	1,258	708
Clothes Dryer	95	95	1,338	735	9,038	1,981
Miscellaneous	100	100	2,603	1,054	33,552	5,610
Cooking	95	96	870	502	5,300	1,408
Refrigerator	67	67	788	669	11,331	3,742
Freezer	67	68	678	677	2,939	1,445
Swimming Pool Pump	93	97	2,475	3,438	4,865	421
Hot Tub Pump	97	NA	816	NA	2,224	NA
Hot Tub Heating	96	NA	477	NA	457	NA
Lighting	80	80	1,413	756	18,216	4,024
Space Heating	76	83	3,223	1,509	2,512	1,872
Furnace Fan	100	100	383	321	2,065	437
Central Air Conditioning	62	61	1,164	358	6,188	413
Room Air Conditioning	92	94	562	411	404	258

Table 7-5: Residential end-use energy consumption forecasting model results for 2050

Residential Energy Requirement	**114,786 GWh**
California Population in 2050	**54,777,700**
Scenario	
UEC =	**OET**
Saturation =	**Continued Trend**
Population =	**CADOF (1/16/06)**
Density =	**Baseline**

	Average Efficiency Adjustment From 2006 (%)		Average UEC in 2050 (kWh/ Household/ Year)		Electric Energy in 2050 (GWh per Year)	
End Use	**Single Family**	**Multi-family**	**Single Family**	**Multi-family**	**Single Family**	**Multi-family**
Water Heating	89	91	2,012	1,617	2,202	1,381
Dishwasher	96	97	318	177	3,279	661
Water Heating - Dishwasher	95	95	962	727	940	481
Clothes Washer	102	102	92	52	1,150	232
Water Heating - Clothes Washer	80	80	925	769	1,006	566
Clothes Dryer	66	67	937	514	6,327	1,387
Miscellaneous	90	90	2,343	949	30,197	5,049
Cooking	95	96	870	502	5,300	1,408
Refrigerator	54	54	631	535	9,064	2,994
Freezer	53	54	542	542	2,351	1,300
Swimming Pool Pump	84	87	2,228	3,094	4,379	379
Hot Tub Pump	92	NA	775	NA	2,113	NA
Hot Tub Heating	91	NA	453	NA	434	NA
Lighting	66	69	1,169	648	15,063	3,451
Space Heating	68	75	2,901	1,358	2,261	1,685
Furnace Fan	92	92	352	294	1,895	401
Central Air Conditioning	45	44	847	258	4,549	304
Room Air Conditioning	83	85	506	370	363	232

Table 7-6: Residential end-use energy consumption forecasting model results for 2050

Residential Energy Requirement	84,187 **GWh**
California Population in 2050	**54,777,700**
Scenario	
UEC =	**Green Dream**
Saturation =	**Continued Trend**
Population =	**CADOF (1/16/06)**
Density =	**Baseline**

	Average Efficiency Adjustment From 2006 (%)		Average UEC in 2050 (kWh/ Household/ Year)		Electric Energy in 2050 (GWh per Year)	
End Use	**Single Family**	**Multi-family**	**Single Family**	**Multi-family**	**Single Family**	**Multi-family**
Water Heating	47	48	1,059	851	1,159	727
Dishwasher	67	68	223	124	2,296	463
Water Heating - Dishwasher	50	50	506	382	495	253
Clothes Washer	107	106	97	54	1,205	243
Water Heating - Clothes Washer	35	35	405	337	440	248
Clothes Dryer	47	48	669	367	4,519	990
Miscellaneous	80	80	2,082	843	26,842	4,488
Cooking	86	86	783	452	4,770	1,267
Refrigerator	34	34	394	335	5,665	1,871
Freezer	33	34	339	339	1,470	1,156
Swimming Pool Pump	74	78	1,980	2,750	3,892	337
Hot Tub Pump	87	NA	735	NA	2,002	NA
Hot Tub Heating	86	NA	429	NA	411	NA
Lighting	30	30	530	283	6,831	1,509
Space Heating	53	58	2,256	1,056	1,758	1,311
Furnace Fan	80	80	307	257	1,652	349
Central Air Conditioning	29	28	532	158	2,909	196
Room Air Conditioning	64	66	393	288	283	181

Table 7-7: Residential end-use energy consumption forecasting model results for 2050

Residential Energy Requirement **67,710 GWh**

California Population in 2050 **54,777,700**

Scenario

UEC = **Green Dream**

Saturation = **Continued Trend**

Population= **CADOF (1/16/06)**

Density = **Increased Multifamily Relative to Single Family**

	Average Efficiency Adjustment From 2006 (%)		Average UEC in 2050 (kWh/ Household/ Year)		Electric Energy in 2050 (GWh per Year)	
End Use	**Single Family**	**Multi-family**	**Single Family**	**Multi-family**	**Single Family**	**Multi-family**
Water Heating	47	48	1,059	851	579	1,607
Dishwasher	67	68	223	124	1,148	1,023
Water Heating - Dishwasher	50	50	506	382	247	560
Clothes Washer	107	106	97	54	603	536
Water Heating - Clothes Washer	35	35	405	337	220	548
Clothes Dryer	47	48	669	367	2,259	2,190
Miscellaneous	80	80	2,082	843	13,421	9,923
Cooking	86	86	783	452	2,385	2,802
Refrigerator	27	27	315	268	2,266	3,309
Freezer	33	34	339	339	735	2,555
Swimming Pool Pump	74	78	1,980	2,750	1,946	745
Hot Tub Pump	87	NA	735	NA	1,001	NA
Hot Tub Heating	86	NA	429	NA	206	NA
Lighting	30	30	530	283	3,415	3,336
Space Heating	81	45	3,439	860	1,312	2,218
Furnace Fan	80	80	307	257	826	841
Central Air Conditioning	38	22	702	141	1,937	434
Room Air Conditioning	64	65	393	311	141	435

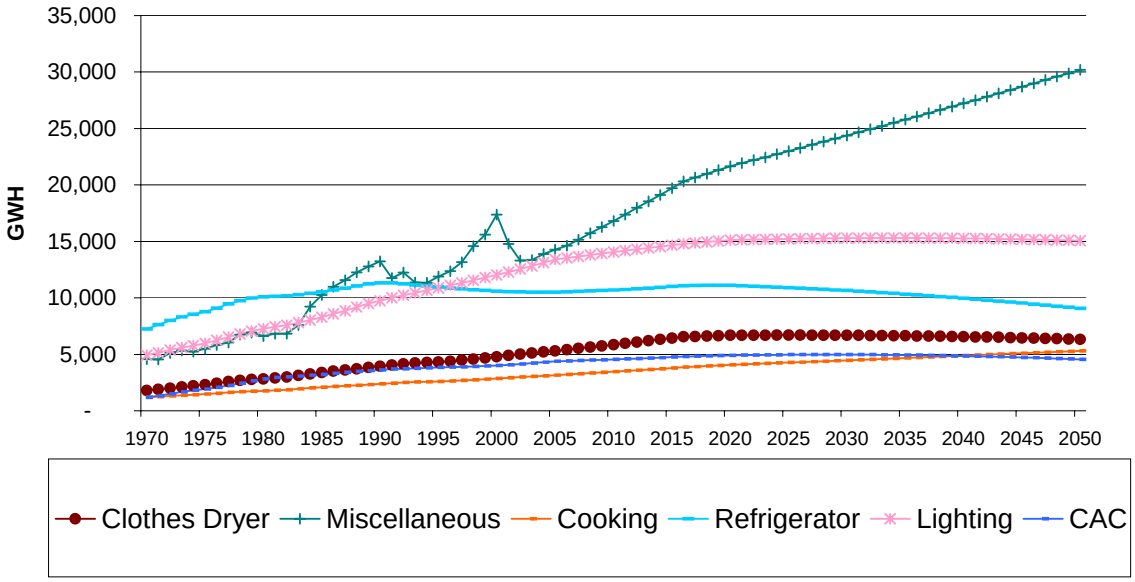


Figure 7-3: Single-family residential electric energy consumption historic and forecast by end-use optimistic efficient technology scenario, part 1

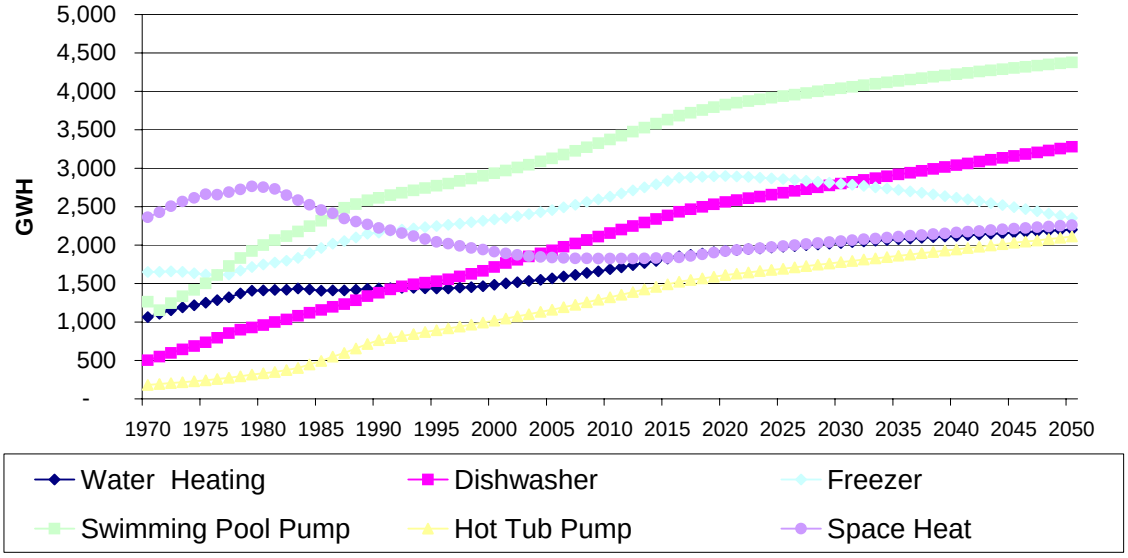


Figure 7-4: Single-family residential electric energy consumption historic and forecast by end-use optimistic efficient technology scenario, part 2

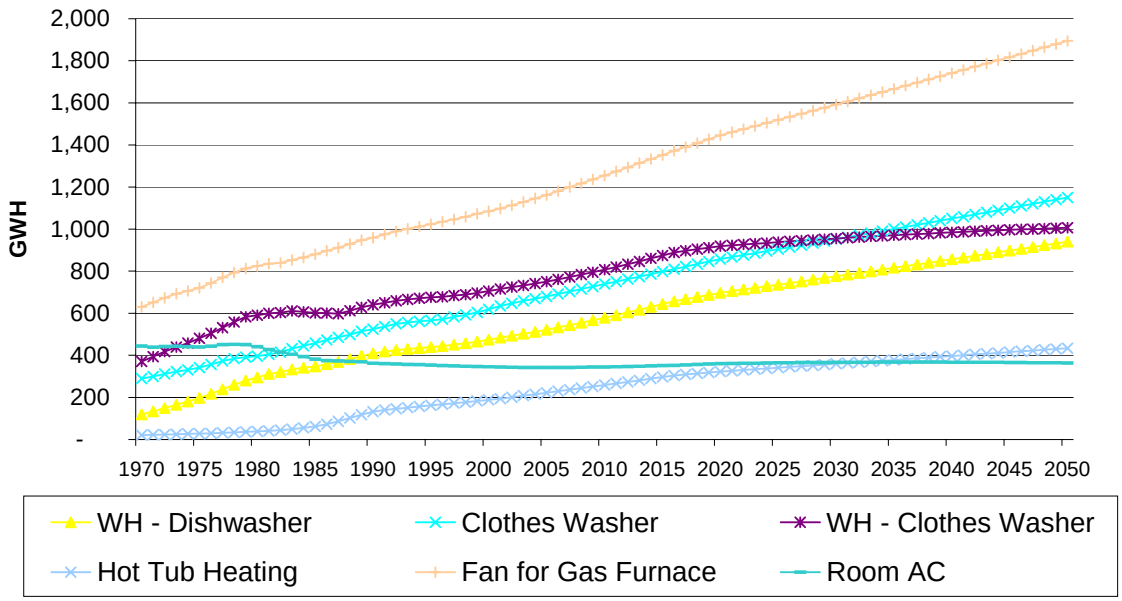


Figure 7-5: Single-family residential electric energy consumption historic and forecast by end-use optimistic efficient technology scenario, part 3

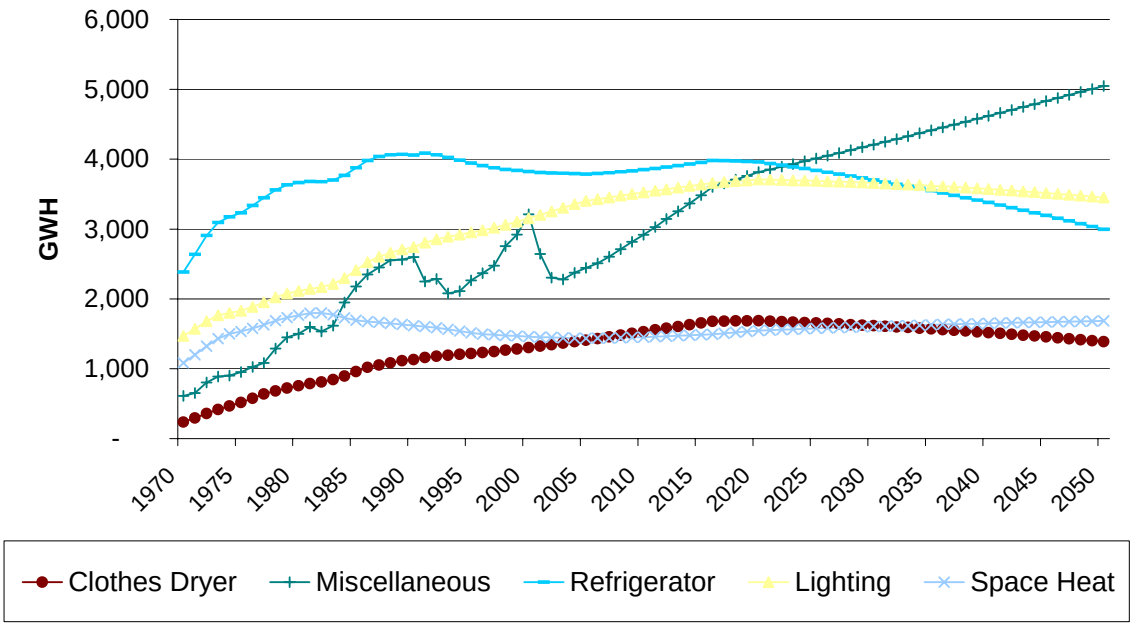


Figure 7-6: Multifamily residential electric energy consumption historic and forecast by end-use optimistic efficient technology scenario, part 1

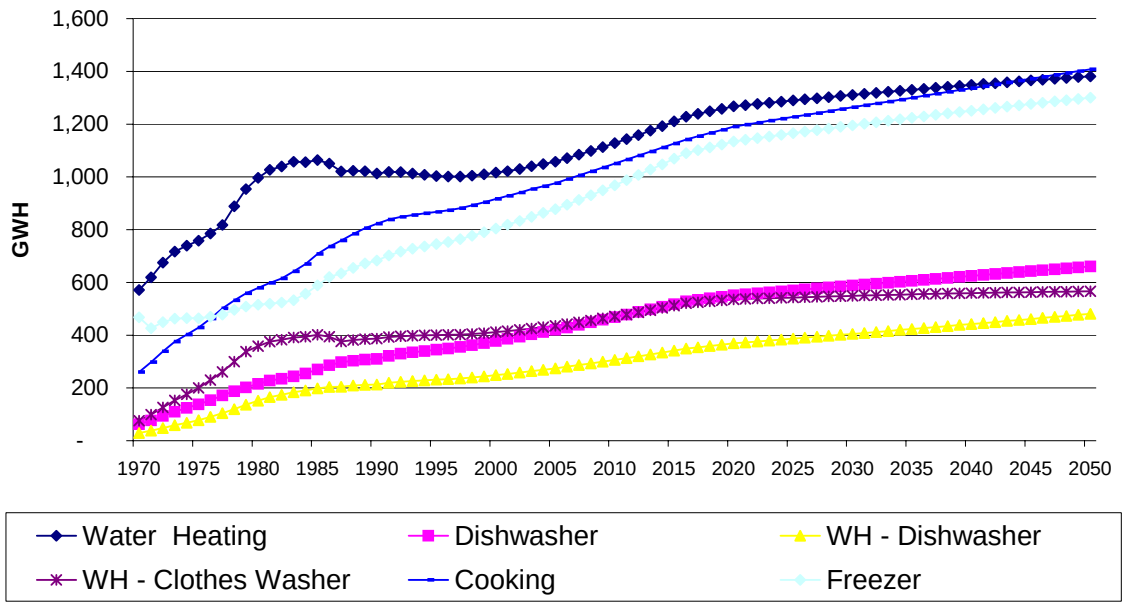


Figure 7-7: Multifamily residential electric energy consumption historic and forecast by end-use optimistic efficient technology scenario, part 2

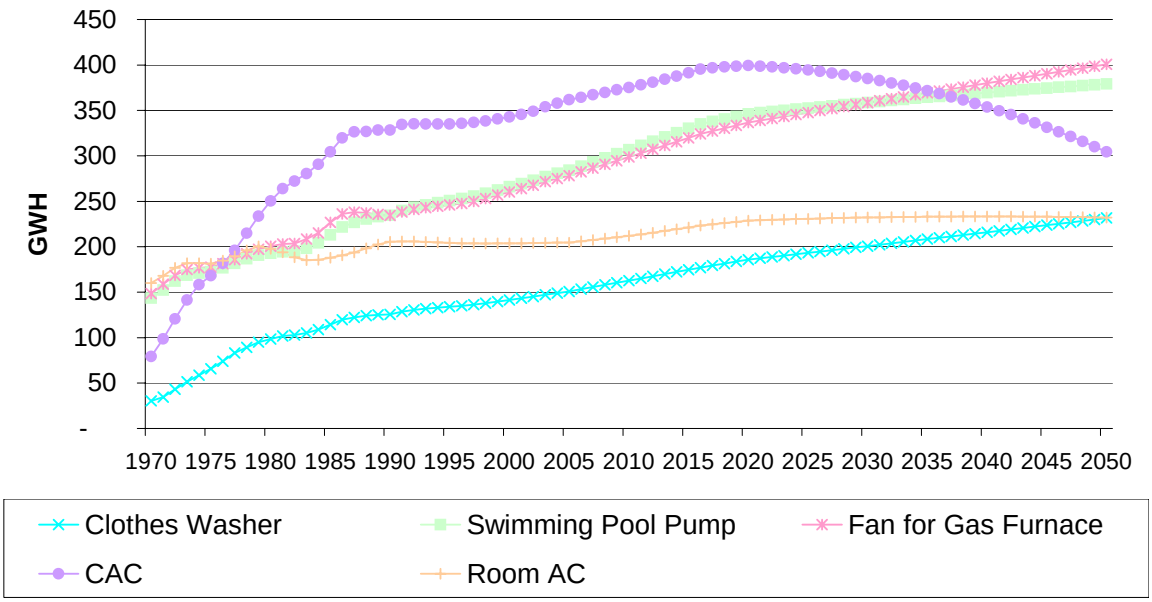


Figure 7-8: Multifamily residential electric energy consumption historic and forecast by end-use optimistic efficient technology scenario, part 3

7.2.1. Effect of Rooftop Photovoltaic Penetration Scenarios

Figure 7-9 and Tables 7-8 through 7-10 show the impact of including two million and five million photovoltaic systems, respectively, along with the other efficiency scenarios. These assumptions represent a market penetration of roughly 10 and 25 percent by 2050. The electricity production associated with these PV scenarios is estimated at roughly 6 and 15 TWh. If counted on the demand side, five million residential photovoltaic systems would reduce net energy consumption in the residential sector in 2050 by about 11 to 18 percent depending on the efficiency scenario, while the reduction associated with two million systems would be four to seven percent.

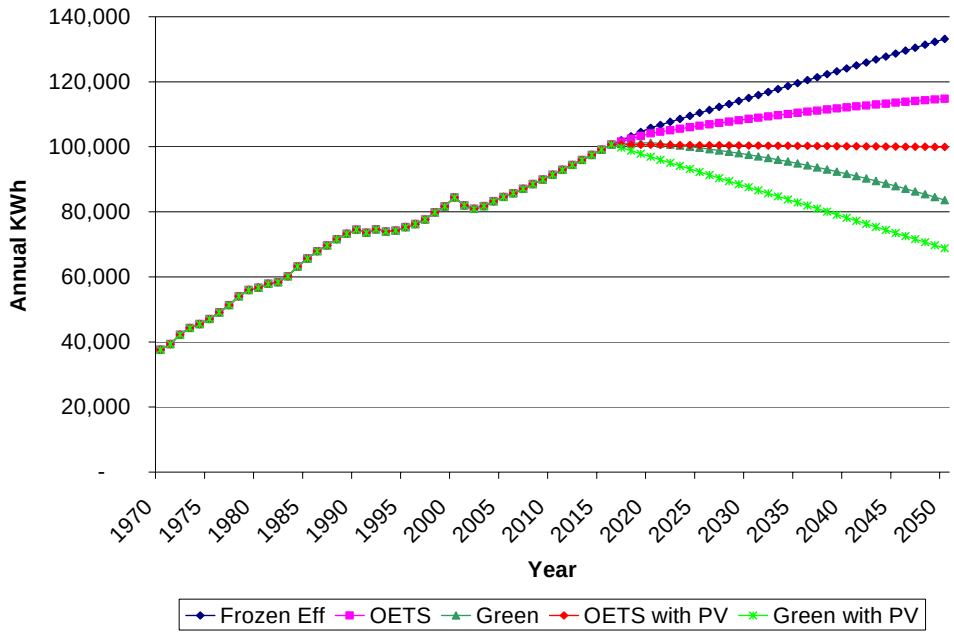


Figure 7-9: California residential electricity consumption to 2050 under efficiency plus PV scenarios with 5 million solar households

Table 7-8: Basic assumptions used In solar PV scenarios

Size (kW)	2.5
Hour per day	5
Days	365
Shading loss	35%

Comparison Data

Year	Pop	HH*	GWh	UEC	Per Capita**
1990	29,828,496	10,305,965	74,528	7,232	2,499
2006	37,297,640	12,236,328	85,743	7,007	2,299

Scenario Data

Growth	Pop	HH
Landis	66,906,185	22,129,160
CADOF	54,777,700	18,211,854

* HH = households

** Per Capita = per person annual energy consumption

Table 7-9: 2,000,000 residential photovoltaic systems installed saving 5,931 GWh per year by 2050

		2050 GWh			2050 UEC			2050 per Capita kWh		
No Photovoltaic Consideration										
Density	**Population**	**OET**	**GD***	**Frozen**	**OET**	**GD**	**Frozen**	**OET**	**GD**	**Frozen**
Baseline	Landis	136,806	99,457	160,718	6,182	4,494	7,263	2,045	1,487	2,402
Baseline	CADOF	114,786	82,680	133,192	6,303	4,540	7,313	2,095	1,509	2,432
Increased multifamily	CADOF	96,171	67,710	109,686	5,281	3,718	6,023	1,756	1,236	2,002
With Photovoltaic Consideration										
Density	**Population**	**OET**	**GD**	**Frozen**	**OET**	**GD**	**Frozen**	**OET**	**GD**	**Frozen**
Baseline	Landis	130,875	93,526	154,787	5,914	4,226	6,995	1,956	1,398	2,313
Baseline	CADOF	108,855	76,749	127,261	5,977	4,214	6,988	1,987	1,401	2,323
Increased multifamily	CADOF	90,240	61,779	103,755	4,955	3,392	5,697	1,647	1,128	1,894

		GWH Change from 1990 (%)			UEC Change from 1990 (%)			UEC Change from 1990 (%)		
No Photovoltaic Consideration										
Density	**Population**	**OET**	**GD**	**Frozen**	**OET**	**GD**	**Frozen**	**OET**	**GD**	**Frozen**
Baseline	Landis	184	133	216	85	62	100	82	59	96
Baseline	CADOF	154	111	179	87	63	101	84	60	97
Increased multifamily	CADOF	129	91	147	73	51	83	70	49	80
With Photovoltaic Consideration										
Density	**Population**	**OET**	**GD**	**Frozen**	**OET**	**GD**	**Frozen**	**OET**	**GD**	**Frozen**
Baseline	Landis	176	125	208	82	58	97	78	56	93
Baseline	CADOF	146	103	171	83	58	97	80	56	93
Increased multifamily	CADOF	121	83	139	69	47	79	66	45	76

* Green Dream

Table 7-10: 5,000,000 Residential Photovoltaic Systems Installed Saving 14,828 GWh per Year by 2050

		2050 GWh			2050 UEC			2050 per Capita kWh		
No Photovoltaic Consideration										
Construction	Population	OET	GD*	Frozen	OET	GD	Frozen	OET	GD	Frozen
Historic	Landis	136,806	99,457	160,718	6,182	4,494	7,263	2,045	1,487	2,402
Historic	CADOF	114,786	82,680	133,192	6,303	4,540	7,313	2,095	1,509	2,432
Higher Density	CADOF	96,171	67,710	109,686	5,281	3,718	6,023	1,756	1,236	2,002
With Photovoltaic sideration										
Construction	Population	OET	GD	Frozen	OET	GD	Frozen	OET	GD	Frozen
Historic	Landis	121,978	84,629	145,890	5,512	3,824	6,593	1,823	1,265	2,181
Historic	CADOF	99,958	67,852	118,364	5,489	3,726	6,499	1,825	1,239	2,161
Higher Density	CADOF	81,343	52,882	94,858	4,466	2,904	5,209	1,485	965	1,732

		GWh Change from 1990 (%)			UEC Change from 1990 (%)			UEC Change from 1990 (%)		
No Photovoltaic Consideration										
Construction	Population	OET	GD	Frozen	OET	GD	Frozen	OET	GD	Frozen
Historic	Landis	184	133	216	85	62	100	82	59	96
Historic	CADOF	154	111	17	87	63	101	84	60	97
Higher Density	CADOF	129	91	147	73	51	83	70	49	80
With Photovoltaic sideration										
Construction	Population	OET	GD	Frozen	OET	GD	Frozen	OET	GD	Frozen
Historic	Landis	164	114	196	76	53	91	73	51	87
Historic	CADOF	134	91	159	76	52	90	73	50	86
Higher Density	CADOF	109	71	127	62	40	72	59	39	69

* Green Dream

7.2.2. Implications of Initial Residential Scenario Results

This section discusses the general policy implications associated with this study's initial scenario results.

7.2.2.1. Frozen Efficiency

This scenario assumes that efficiency improvements are limited to those already in place on the margin for new appliances, new homes, and major renovations. Most of the improvements on the margin are associated with codes, standards, and current market-based efficiency levels. Although the rate of growth in consumption slows under this scenario as compared to the period 1970 to 2005, this is also partly due to the assumption

that the rate of growth in home size and the "Miscellaneous" end use decreases over the forecast period. If growth in home size and the "Miscellaneous" end use do not slow, new policy interventions may be needed simply to keep consumption levels from exceeding those in this forecast.

7.2.2.2. OET

Under this scenario, California would need to pursue energy-efficiency policies at least consistent with, and likely more aggressive than, those presently in place. There will need to be periodic updates to energy-efficiency standards, increased and improved enforcement of those standards, and continued support for public goods and utility-procurement funded efficiency programs. Significant continued improvements in efficiency levels for key end-uses as well as increased motivation among consumers to adopt high-efficiency products will be needed. Given consumers' historically high implicit discount rates, the current low consumption levels of many residential end uses, current estimates of the value of avoided electricity, and current electricity prices, the increased adoption levels associated with this scenario would likely require increases in real electricity prices, higher valuation of avoided electricity, or a greater shift toward decision making based on socio-environmental concerns rather than individual well-being.

7.2.2.3. Green Dream

Under this scenario, California would almost certainly be required to pursue polices that give preference to energy efficiency over other issues. Appliance and homebuilding standards would need to be extremely stringent, continuously increased and rigorously enforced. It is likely that a significant carbon tax, higher electricity price or equivalent indirect incentives would be needed to both radically increase consumer adoption of extremely efficient technologies and motivate the increased research and development necessary to develop and commercialize them. Policies might also be needed to promote greater housing density and smaller homes, construction methods that employ passive cooling and shading, appliance size or feature constraints, virtual elimination of secondary refrigerators, increased daylighting, the elimination of standard efficiency incandescent light bulbs and deployment of effective lighting controls. While the efficiency advances included in this scenario are plausible within existing technology paradigms, they push toward the upper end of what many technologists believe is possible in this time frame and go well beyond what would be considered cost-effective under current avoided cost valuations.

In summary, study results show that even if energy efficiency improvements continue to provide significant reductions in electricity consumption through 2050, aggregate consumption also continues to increase due to increasing population and energy service demands. Under the Green Dream scenario, residential electricity consumption is reduced by 2050 to today's level. However, this scenario requires reducing per capita consumption by almost 40 percent, which would be an unprecedented accomplishment. Continuation of existing efficiency programs and standards, along with new, much more aggressive policies and a change in consumer adoption behavior, would likely be necessary to achieve these reductions.

8.0 Recommendations for Future Research

This study was intended to provide the initial step of a broader process to extend energy forecasting for California's buildings and industrial sectors to the long-term time scales associated with economic models of climate change. As documented herein, this study focused on the residential electricity sector, at an end-use level of analysis, over a forecast horizon ending in 2050, using scenario analysis to document assumptions and estimate a range of possible futures. This study has produced a flexible end-use scenario analysis model that can be easily used for further scenarios and testing of alternative assumptions.

A number of further research activities should be considered, including the following:

- Consider expanding the analysis to other sectors (e.g., commercial, industrial, and agricultural) and other fuels (e.g., natural gas).
- Consider adding more technology-specific details to the end-use level forecasts. This initial effort included extensive review of secondary sources and limited interviews with technology experts. This effort also focused on simply developing target end-state efficiency levels within end uses. Future efforts should consider expanding the number of expert interviews conducted within end uses (including, possibly, the use of formal Delphi surveying techniques) and providing additional documentation and analysis of the possible combinations of energy efficiency measure characteristics necessary to achieve the end-state efficiency levels.
- Future analyses should consider adding energy efficiency measure cost forecasts, retail fuel forecasts, end-user adoption modeling, and explicit modeling of market interventions (e.g., codes and standards, incentive programs, cost adders, tax incentives).
- Related to the previous recommendation, future studies should consider incorporating full stock accounting algorithms into the long-term models.
- Consider efforts to develop explicit linkages and integration between long-term electricity and natural gas consumption and economic (e.g., computable general-equilibrium) models.

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10.0 Glossary

ACEEE	American Council for an Energy Efficient Economy
CADOF	California Department of Finance
CFL	compact fluorescent lamp
CLASS	California Statewide Lighting and Appliance Saturation Study
CSI	California Solar Initiative
CSSC	conservation supply curves
GHG	greenhouse gas
GWh	gigawatthour
HVAC	Heating, Ventilating, and Air Conditioning
kWh	kilowatthour
LBNL	Lawrence Berkeley National Laboratory
LED	light-emitting diode
MEF	modified energy factor
NAHD	National Association of Home Builders
OET	Optimistic Efficient Technology
PIER	Public Interest Energy Research
PNNL	Pacific Northwest National Laboratory
PV	photovoltaic
RAC	room air conditioners
SEER	seasonal energy efficiency ratio
TWh	terawatthour
UEC	Unit energy consumption