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Using energy scenarios to explore alternative energy pathways in California

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Abstract

This paper develops and analyzes four energy scenarios for California that are both exploratory and quantitative. The business-as-usual scenario represents a pathway guided by outcomes and expectations emerging from California's energy crisis. Three alternative scenarios represent contexts where clean energy plays a greater role in California's energy system: Split Public is driven by local and individual activities; Golden State gives importance to integrated state planning; Patriotic Energy represents a national drive to increase energy independence. Future energy consumption, composition of electricity generation, energy diversity, and greenhouse gas emissions are analyzed for each scenario through 2035. Energy savings, renewable energy, and transportation activities are identified as promising opportunities for achieving alternative energy pathways in California. A combined approach that brings together individual and community activities with state and national policies leads to the largest energy savings, increases in energy diversity, and reductions in greenhouse gas emissions. Critical challenges in California's energy pathway over the next decades identified by the scenario analysis include dominance of the transportation sector, dependence on fossil fuels, emissions of greenhouse gases, accounting for electricity imports, and diversity of the electricity sector. The paper concludes with a set of policy lessons revealed from the California energy scenarios.

Keywords: Energy scenarios; California; Energy forecasting

> No amount of sophistication is going to allay the fact that all your knowledge is about the past and all your decisions are about the future (Wilson, 1975).
>
> It is far better to foresee even without certainty than not to foresee at all (Poincare, 1913).

1. Introduction

In early 2001, electricity blackouts and high-energy prices in California brought energy issues to the forefront of public attention. While the visibility of the crisis highlighted numerous immediate inadequacies in the state's energy system, it also revealed deeper needs for innovative and systematic approaches to energy analysis—both within California and in other domestic and international contexts. The crisis illuminated the relevance of alternatives to business-as-usual (BAU) trends and possibilities for expected and unexpected change. Consideration of alternative energy pathways is critically important to California's uncertain and changing energy context. Alternative pathways are increasingly important if California is to adequately balance its energy needs with other economic, social, environmental, and land use interests, especially with a growing population and economy.

Successful long-term energy policy and planning requires systematic information that connects current choices and uncertainties with their potential implications for the future. In California, a substantial body of information exists on specific dimensions of its energy system, such as market analyses, energy and price forecasts, and energy efficiency studies.[1] In addition, an abundance of articles and reports have sought to analyze and interpret the implications of California's electricity crisis. In many cases, however, the available energy literature offers highly specific information

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[1] A detailed summary of California energy references is provided in Appendix B.

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oriented to expert audiences or provides news-based information that gives little insight into the deeper driving forces or broader consequences of existing conditions. Available information is often poorly equipped to explore processes of change, aggregate outcomes, and unexpected results. Thus, the challenge is to develop techniques and information sharing that can connect available information, immediate concerns, and desired outcomes for effective decision-making.

This article presents energy scenarios as a useful method for exploring energy choices in California from a long-term and systematic perspective. Considerable discussion and analyses have focused on global and US energy scenarios,[2] however this study is unique in developing and analyzing energy scenarios for California. The significance of California's energy choices both inside and outside of the state makes this study relevant to a broader domestic and international audience. Within the US, California is the most populous and economically productive state and has been a leader in national energy policy. California is also the fifth largest economy in the world, ranks tenth in terms of primary energy consumption, and approximately fifteenth in terms of greenhouse gas emissions.[3] With a history of being on the vanguard of energy policy and with one of the most scrutinized set of electricity sector reform policies enacted in the world, California's energy choices and outcomes promise to continue to influence the direction of deregulation and energy policy in US and other countries.

This paper develops and evaluates four California energy scenarios that explore a range of possible future energy pathways. The BAU and three alternative energy scenarios developed in this paper combine narrative and modeling methods to illustrate alternative contexts and analyze potential outcomes. The BAU scenario represents a pathway guided by outcomes and expectations following the energy crisis. Three alternative scenarios represent contexts where clean energy plays a greater role in California's energy system: Split Public is driven by local and individual activities; Golden State gives importance to integrated state planning; Patriotic Energy represents a national drive to increase energy independence.

The first section of this paper introduces the energy scenario approach and situates this method within the context of energy analysis. It contrasts energy forecasts and scenarios and provides a foundation for using scenarios to explore a range of possible energy pathways for California. The second section uses a distinct methodology to develop the BAU and three alternative scenarios around critical uncertainties in California's energy system. In the third section, the implications of the scenarios are examined using energy modeling techniques to quantitatively evaluate future energy consumption, composition of electricity generation, energy diversity, and greenhouse gas emissions associated with each scenario through 2035. The paper concludes by presenting a set of critical issues and policy implications illuminated by the analysis.

There are many opinions about the plausibility of different energy scenarios in technical, economic, and political terms. This article does not claim that the scenarios presented here are the most likely or most desirable, as predicting the future with accuracy is not really possible (Craig et al., 2002). Instead, this article should be read as an exploratory exercise aimed at developing a set of scenario analysis tools and initiating a discussion on alternative future energy pathways. The details of this analysis are important, and there is likely to be a range of opinion on the plausibility of different elements comprising each scenario. However, the broader intention of exploring current opportunities and challenges should not be lost to differing opinions on the details. It is our aim that this paper opens the doorway for greater discussion, debate, and comparison from many perspectives on alternative energy pathways in California.

2. The scenario approach

This paper integrates aspects of strategic planning and energy analysis to develop scenarios that are exploratory and analytical. The development of scenario methods as a strategic management and organizational learning tool were pioneered by the business community in the 1960s. Strategic management studies of scenarios have described how the process of developing well-researched and plausible stories about the future can facilitate organizational learning and generate critical insights into strategic decision-making. Many of the notable figures in this area come from a core group of ex-Royal Dutch/Shell scenario planners who have played a prominent role in articulating scenario techniques to a wider audience.[4]

In energy research, scenarios are most commonly used to characterize an envelope of expected future conditions or quantify savings potentials from policy, technology, or behavioral changes. Scenarios have gained prominence within the fields of climate change and energy efficiency. Notably, the Climate Change Emissions Scenarios of the Intergovernmental Panel on Climate Change (IPCC) play an influential role in both

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[2] For example see Interlaboratory Working Group (2000), NEP (2002), Reddy et al. (1997), and World Energy Council (2000).

[3] Greenhouse gas emissions estimate is based on the following data sources: CEC (2002f), EIA (2001f,h), and LAEDC (2001).

[4] A well-known example is Schwartz' book, *The Art of the Long View*; one of the most popular books on the topic of strategic scenarios (1991).

climate change science and policy (Nakicenovic and Swart, 2000). The report, *Scenarios for a Clean Energy Future*, prepared by an interlaboratory working group of US national labs, also represents a substantive use of scenarios in interdisciplinary energy analysis. It analyzes the effects of three different public-policy scenarios on the growth of energy consumption and carbon dioxide emissions over the next 20 years (Interlaboratory Working Group, 2000). Both of these examples reflect a growing effort by energy researchers to address uncertainty and incorporate broader dimensions of society and technological change into their scope of analysis.

In this paper, the term "energy scenarios" refers to a set of illustrative energy pathways that are created using a distinct scenario development methodology and quantitatively analyzed using energy modeling techniques. The scenario stories provide a set of alternative contexts for exploring different ways that the future may unfold. Energy modeling evaluates the systematic changes and impacts resulting from each scenario on California's energy system over the next few decades (Fig. 1).

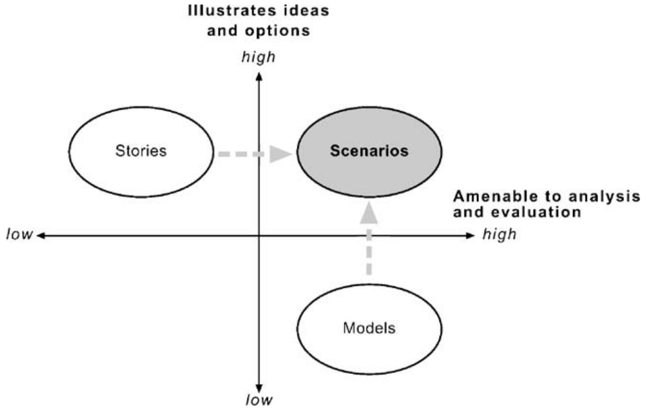

Fig. 1. Energy scenarios examine a range of possible outcomes that are grounded within system dynamics of the energy system. Combining stories and models, scenarios qualitatively explore diverse contexts and quantitatively evaluate potential outcomes.

Scenarios are distinct from forecasts in that they explore a range of possible outcomes resulting from uncertainty; in contrast, forecasts aim to identify the most likely pathway and estimate uncertainties. As a result, forecasting models are most effective under conditions when information availability is extensive and understanding of governing dynamics is high. However, when systems are less well defined and interrelationships between factors are less stable and predictable, energy forecasts have shown themselves to be poorly equipped to characterize processes of change. A recent review of energy forecasts over the last 50 years in the US showed that historical forecasts have routinely failed to represent actual conditions by systematically overestimating consumption and underestimating uncertainties (Craig et al., 2002).

This paper integrates stories and models into a set of scenarios that explore alternative energy pathways for California in a way that highlights a range of possible conditions and maintains consistency with physical dynamics of the state's energy system. Drawing from Gallopin and Raskin, scenario narratives provide "texture, richness, and insight" while models offer a level of "structure, discipline, and rigor to the analyses of socioeconomic, resource, and environmental conditions" (Gallopin and Raskin, 1998). Scenarios do not try to account for every possible outcome, rather they focus on developing a set of insightful lenses for exploring processes of change (Table 1).

3. Developing the exploratory scenarios

The objective of developing scenario storylines is to create bounded contextual frames for exploring the future energy system from different perspectives. This section reviews the development of four California energy scenarios using a six-step process adapted from

Table 1
Contrasting energy forecasts and energy scenarios

	Forecasts—*What is likely?*	Scenarios—*What could be?*
Approach	Rational focus on analysis and outcomes	Focus on process, strategy, and learning
Objective	To develop most likely pathway and characterize uncertainty	To develop a number of insightful pathways that explore uncertainties
Methods	Analytical models and driver variables	Qualitative stories evaluated by models
Treatment of uncertainty	Probabilistic methods, statistics, and transparency of assumptions	Exploration of critical uncertainties, and separation of predetermined and uncertain elements in crafting stories
Important actors	Reliance on experts, state and national planning agencies	Group facilitators, strategists, problem-solvers

Table 2
Six-step process for developing scenarios

1. Define a focal issue
2. List important forces in the environment
3. Evaluate forces by importance and uncertainty
4. Select a scenario logic
5. Develop scenarios around critical uncertainties
6. Evaluate the implications of the scenarios

Adapted from Schwartz (1991).

Table 3
Examples of important factors in California's energy system

Future form of power purchase/market structure
Dominance of economic costs versus other metrics (air quality, energy diversity, etc.)
Agents of leadership—public, municipalities, state, federal
Prominence and interpretations of security-energy linkages
Reliance on electricity imports from other states
Perception of distributed generation benefits/costs
Balance between supply and demand focus
Strength of state energy regulatory authority
Public view of energy choices as personal responsibility versus paternalistic provision
Strength of community, consumer, non-government organizations
Relative growth and composition of the state economy
Level of interest in energy infrastructure improvements
Target of technology support—R&D, demonstration projects, market pull/push, institutions
Motivation for developing hydrogen based technologies and infrastructure
Facility of interconnection for distributed generation
Fuel price and supply volatility versus stability
Electricity cost recuperation of long-term contracts

Schwartz (1991) that is outlined in Table 2. This process involves identifying, prioritizing, and negotiating the most interesting, uncertain, and important elements in the state's energy system.

This section develops four different scenarios to explore underlying tensions, opportunities for change, and ways that uncertainties may play out in different ways in California's energy system. It aims to show the significance of each scenario and elaborate underlying assumptions. This methodology is one of many possible approaches that may be used to generate many potential stories. The four scenarios presented here aim to give insights into potential energy pathways in California.

Step 1: *Defining a focal issue*. The first step in developing scenarios identifies a unifying question or idea to define what the scenarios will explore. Scenarios provide alternative organizing frames for evaluating and assembling information relevant to the focal issue, where each scenario represents a different perspective on the issue. In our analysis, the focal issue poses a set of questions about clean energy and possible alternative pathways in California:

> *California Energy Scenarios Focal Issue*—How might cleaner energy pathways develop in California? What will be the drivers of change over the next decades? How could California's energy system differ from business-as-usual expectations?

The focal issue reflects an important set of uncertainties in California's future energy pathway. Profound changes in California's energy pathway, accelerated by deregulation and the state's energy crisis, challenge the likelihood of BAU pathways. These transformations highlight the relevance of exploring alternative energy pathways.

Step 2: *Determining the important factors in the system*. Armed with a compelling focal issue and system to investigate, the next step elaborates a list of important factors in California's energy system. The goal of this step is to define the universe of interactions and elements that may be considered in the scenarios. It is useful for determining what information is relevant to the analysis and where there are gaps in understanding. Used in a participatory context, this step can be used to bring multiple perspectives to bear on a single focal issue. Our analysis created a list of over one hundred important factors shaping California's energy system. Table 3 presents a truncated list of some of the many important factors.

Step 3: *Evaluating forces by importance and uncertainty*. The highly interconnected nature of social, political, economic, and technical dimensions of the state's energy system means that the list of important factors created in step two is long and composed of interrelated concepts. Step three identifies and then evaluates driving forces underlying factors listed in step two. Fig. 2 presents these fourteen driving forces. The figure evaluates each driving force by relative importance and uncertainty in the state's energy system. The driving forces in the upper right of the figure are the most important and highly uncertain and are labeled as critical uncertainties in California's energy system. They include: the relevance of energy diversity, relative attention to oil and transportation, long-term prominence of energy and security, types of clean energy activities, and role of distributed generation. The critical uncertainties form the basic themes and tensions for the scenario storylines.

Step 4: *Selecting the scenario logic*. In developing scenarios, critical uncertainties illuminate and organize the foundational themes for the scenario storylines, with each scenario engaging with the critical uncertainties in different ways to generate alternative energy pathways. Step four describes a logical relationship between the four scenarios that is linked to three basic questions about the importance of energy diversity, the role of government involvement, and scale of primary influence in California's future energy pathway. The scenario logic chain and key branch points are shown in Fig. 3. At the first point of divergence, each of the three alternative scenarios represents a context where energy

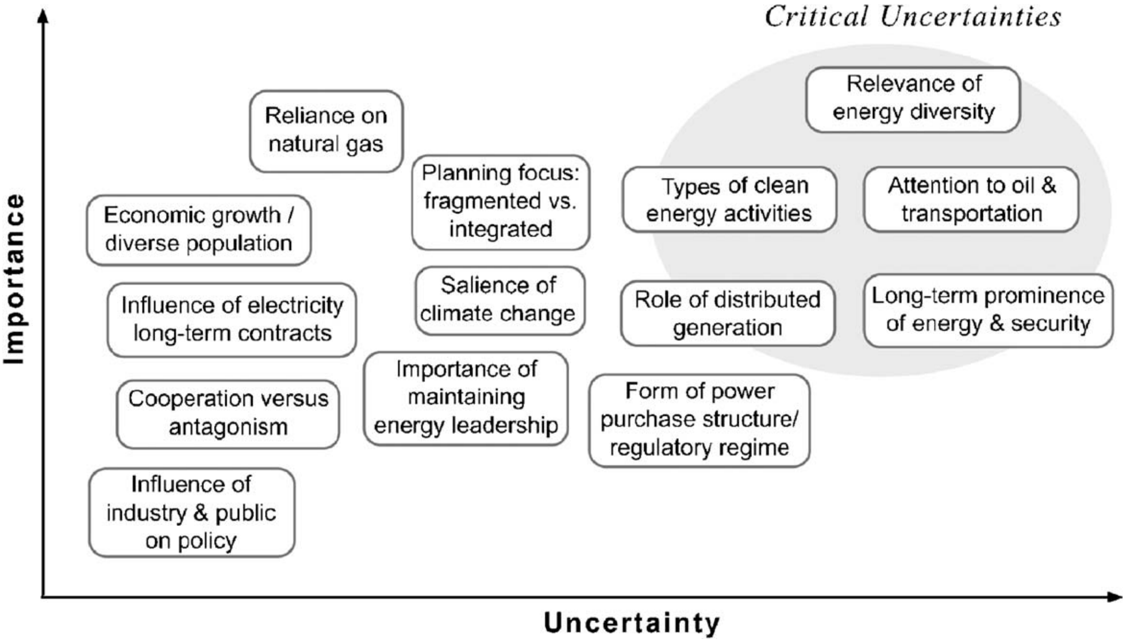

Fig. 2. Identifying and evaluating driving forces in California's energy system by importance and uncertainty. The most important and most highly uncertain driving forces are categorized as critical uncertainties in California's energy system. The five critical uncertainties highlighted in this figure form the underlying themes of the scenario storylines.

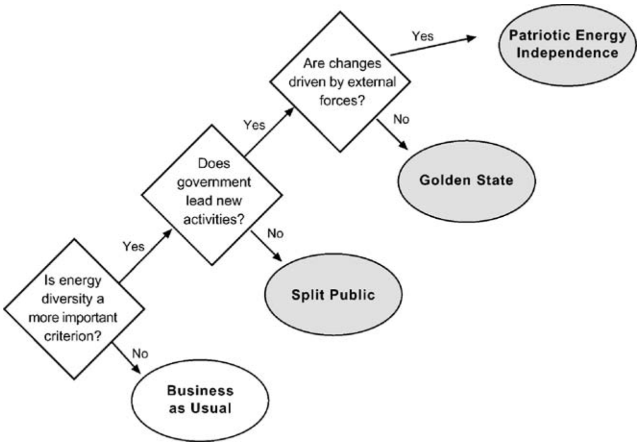

Fig. 3. Scenario branch points in California's future energy pathway. The logic connecting the alternative energy scenarios to the BAU energy pathway is linked to three fundamental questions that form central points of divergence and relation for the energy scenarios.

diversity gains prominence compared to BAU conditions. At the second point of divergence, clean energy activities in Split Public are led by active segments of the public rather than government policies or activities. In Golden State and Patriotic Energy, government plays prominent roles in leading new clean energy activities. At the third point of divergence, Golden State is driven by forces internal to the state's energy planning context. An era of energy leadership and cooperation emerges from integrated state energy planning. Patriotic Energy is a scenario driven by external changes to the US energy pathway under an increasingly hostile and insecure international world order. Together the scenarios explore a range of different potential driving forces and contexts for change.

Step 5: *Develop stories around critical uncertainties*. Step five composes storylines for each scenario describing how the future may unfold. Each story illuminates different dimensions of the unifying focal issue. Together the scenarios reflect many of the driving forces with potential to reshape California's pathway. None of these stories represents an ideal outcome or realization of the full potential of clean energy. Instead the scenarios explore different contexts where new priorities may emerge. These stories aim to inspire discussion about alternative future pathways and expand exploration beyond BAU forecasts.

4. Base case storyline—BAU scenario

The BAU scenario depicts a world formed by the convergence of historical trends with outcomes and expectations following California's energy crisis in 2000–2001. In the BAU context of post-deregulation uncertainty, California develops neither an integrated logic nor a unified vision for the future and instead reflects crisis-inspired growth of the electricity sector and continuation of historical trends in the residential, transportation, commercial, and industrial sectors. State government struggles to establish a clear regulatory framework, harmonize intra-agency and intra-branch power struggles, and address concerns beyond immediate issues. Without energy in the spotlight, individuals revert to pre-crisis preferences and activities.

Changes in the residential, transportation, commercial, and industrial sectors are shaped by incremental trends rather than totally new activities. Steady growth in population, development of the economy, and per capita transportation activity characterize the BAU pathway. The state economy grows at a rate slower than in the late 1990s, but steadily enough for consumers to increase the size of their homes, buy new cars, drive more, and use bigger and better appliances.

Public opinion about energy reflects little personal connection to energy choices and outcomes. Consumers express the attitude, "let's pick up where we left off before the crisis". Bigger cars and SUVs continue to gain market share, and people generally feel entitled to consume what they can afford. Hybrid and electric vehicles slowly gain visibility in the BAU scenario, but gains are largely isolated to wealthier urban and suburban areas of the state and remain marginal compared to overall activity.

The transportation sector reflects increases in transportation activity and population growth without major changes to transportation technologies. Competitively priced alternative transportation options remain limited. Instead, light-duty trucks and sport utility vehicles continue to gain popularity and become an increasing share of total passenger vehicles. The overall national transportation policy context remains resistant to increases in vehicle fuel economy and alternative transportation technologies. As a result, the national fuel economy standard of gasoline and diesel passenger and freight vehicles does not change and the overall fuel economy of California's passenger vehicle fleet decreases.

Under BAU conditions, the private sector completes construction of a large fraction of the natural gas power plants approved during and immediately following the energy crisis. Long-term electricity contacts negotiated during the energy crisis define much of the composition of electricity generation over the next 10 years. The relevance of this expectation is evidenced by a recent study showing that an estimated 60% of the long-term electricity contracts negotiated with the Department of Water Resources during the energy crisis were for natural gas power plants that had not yet been built (Bachrach, 2002). The BAU scenario incorporates assumptions of significant new electricity capacity additions using the levels of capacity additions from the California Energy Commission's *2002 Electricity Outlook* (CEC, 2002b, Tables I-2 and II-2-1). Limited numbers of state-supported renewables projects maintain capacity levels similar to historic levels, however electricity diversity decreases overall.

5. Alternative storyline 1—Split Public scenario

In the Split Public scenario, a motivated segment of the public contests the BAU world around them and begins to organize and initiate clean energy activities on individual and local levels. Responding to calls for public leadership, self-labeled "progressive energy enthusiasts" promote activities in the domains where they exert influence and control—in households, consumer preferences, and communities. Split Public highlights public interest as a critical agent in California's future energy pathway.

The residential, transportation, and commercial sectors become sites of new activities. Hybrid and electric vehicles, solar water heaters, energy efficient lights, solar home systems and municipal renewable energy projects proliferate in up to 50% of households and communities in California by 2035. Municipal energy campaigns and directed renewable energy initiatives become important new avenues for interested citizens and organizers to extend public influence. San Francisco becomes a leader in municipal, commercial, and residential solar and wind energy generation. In addition, cities become key arenas of organizing climate change mitigation policies, and many California cities reduce carbon dioxide emissions to below 1990 levels.

Despite dynamism in certain areas, the reach of Split Public is limited by a lack of additional cooperation by state government, national policy, and the private sector. Without state government and private sector engagement, industrial energy and larger-scale electricity generation are outside of local control and remain unchanged from the BAU scenario. In addition, without changes to national transportation policy, vehicle fuel economies stagnate and fuel cell technologies remain in the domain of research. Split Public is a scenario that explores how a set of energy activities motivated by individual and community interest can influence California's energy pathway.

The relevance of this scenario is highlighted by actual public-initiated energy activities since the energy crisis. For example, the California's Energy Commission's Emerging Renewables Buy-Down Program has received a dramatic increase in interest from electricity customers since the energy crisis[5] (CEC, 2002e). In addition, in November 2001, residents of San Francisco passed city propositions B and H which are expected to provide financing for 60 MW of solar and 30 MW of wind power (California Solar Center, 2002a, b). The state also recently eliminated a sunset clause on net metering authorization, thereby extending authorization for

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[5] The California Energy Commissions Emerging Renewables Buydown Program offers $4500/kW or 50% off the system purchase price of new small-scale renewable energy electricity-generating systems (CEC, 2002e).

systems up to one megawatt indefinitely (California Legislative Counsel, 2002, Assembly Bill 58). In addition, much of the demand reduction during the electricity crisis is attributed to voluntary energy efficiency measures by individual households. All of these activities point to the importance of public action in California's future energy pathway.

6. Alternative storyline 2—Golden State scenario

Golden State is a scenario of coordinated activity on individual, local, and state levels. Rallying around California's historic sense of pride in progressive energy technology and policy, earlier fragmentation and crisis give way to a new era of cooperation in energy and resource planning. The lessons learned from the electricity crisis become significant driving forces for new visions about the future. Golden State combines active state energy policy with individual and community activities.

The collapse of a prominent energy company, decreasing shareholder confidence, and concerns over corporate accounting draw attention to the importance of achieving a balance between energy sector reform, individual actions, and state-led policy in California's energy pathway. Golden State is simultaneously an aggressive scenario for diversification of the electricity sector and a moderate scenario for individual and local clean energy activities.

Golden State incorporates the residential, transportation, and community-led activities of Split Public. However, these changes are adopted more slowly than in Split Public through participation and public outreach to reach levels of 30% of households by 2035. Golden State combines these activities with a progressive state energy policy and planning mandate focused on diversification and emissions reductions in its electricity sector. To achieve these objectives, state agencies undergo significant reorganization to consolidate, integrate, and reassert authority to collect energy information and initiate long-term policy and planning.

New natural gas power plant construction decreases to half of the construction levels proposed in the BAU scenario. A 20% Renewable Portfolio Standard (RPS) becomes the flagship energy policy to create viable and competitive renewable energy markets. The state meets and maintains the 20% goal by incorporating significant new renewable-based electricity generation primarily in the form of wind, geothermal, and biomass to serve future demand and to decrease imports. Consequently, California leads the nation in achieving renewable energy targets and setting carbon dioxide emissions reductions commitments in electricity generation.

While Golden State makes a leap forward in terms of participatory planning, without additional national policy support, it is unable to realize more extensive changes in the transportation sector. Golden State does not create sufficient market-pull or push to develop hydrogen-based fuel cell transportation technologies. Golden State adopts existing alternative transportation technologies like hybrid, electric, and natural gas personal vehicles and public transit vehicles to levels of 30% by 2035. However, lacking national transportation policy, the fuel economy of gasoline and diesel passenger vehicles and freight vehicles continue to stagnate. Increasing activity and population offset many of the gains in fuel economy from alternative transportation activities.

Golden State explores how an extensive set of renewable energy activities in electricity generation together with individual and community activities might affect the future of California's energy system. The new California RPS is an indication of greater state interest in diversification of the electricity sector. Passed into law in September 2002, the California RPS is one of the strongest state RPS policies in the country (California Legislative Counsel, 2002, Senate Bill 1078). It mandates that the fraction of renewable energy-based electricity sold by utilities and private retailers in the state increase 1% per year to a 20% renewable market share by 2017. The policy promises to be the catalyst of dramatic new changes in California's electricity sector and suggests greater state-level intentions to support renewable energy in the future. Golden State is an insightful scenario for exploring a pathway of diversified electricity generation.

7. Alternative storyline 3—Patriotic Energy independence scenario

Facing a world of international insecurity, Patriotic Energy reflects a national drive for greater energy independence. Patriotic Energy is a world of aggressive energy activities and policies, particularly in the transportation sector, as the country seeks to reduce its dependence on imported oil. National policy and patriotism create powerful drivers for an energy independence movement within the US. This national vision creates a complete reframing of issues of energy, resources, and the environment, creating new alliances and reinterpretations of the American way of doing things.

In Patriotic Energy Independence, the availability of a continuous flow of cheap oil becomes increasingly threatened. With numerous forces converging to challenge the political and economic conditions in the US, maintenance of good relations with oil producers becomes an increasingly critical foreign policy challenge. In this changing world, decreasing oil dependence becomes a central pillar of national security policy. In the near term, the US focuses on the development of domestic energy resources—national coal, oil, and natural gas are exploited with the best available technologies. Development of a hydrogen economy becomes a unifying national vision for the future.

Massive government investment is directed at development of an oil-independent transportation system. The President calls upon the US public to embrace the new American dream and buy new low-oil consuming cars. Existing hybrid and electric vehicle technologies become critical features of the near-term strategy for reducing transportation oil consumption. National energy policy mandates increases in fuel economy standards for passenger and freight trucks. Critical to mid-term strategy, the US provides substantial support for research, development, and commercialization of direct hydrogen fuel cell vehicles. The first fuel cell vehicles are available for commercial sale in the middle of the analysis period; by 2035 they comprise 75% of passenger vehicles on the road.

Renewable energy becomes a strategic resource for generating electricity, for producing hydrogen gas, and for freeing up domestic natural gas for high value uses. Patriotic Energy reduces new natural gas power plant construction to 50% of the BAU scenario, filling additional capacity needs with renewable energy-based generation. A national RPS is implemented that mandates 20% renewable energy-based electricity market share by 2020. California becomes ideally positioned to lead US states in the production of renewable energy-based electricity using wind, geothermal, and biomass and to a lesser extent solar and small-hydro.

Patriotic Energy Independence reflects conditions which radically reframe individual activities. It incorporates the residential and commercial sector activities of Split Public; however in this case, they are motivated by a sense of civic responsibility. Solar home systems become symbols of household patriotism. Smart cars, hybrids, electric, and later fuel cell vehicles dominate the roads. Diversification beyond fossil fuels becomes a driving force and strategic priority across individual, community, state, and national scales. The relevance of the Patriotic Energy scenario is reinforced by the current foreign policy context that has increased the visibility of energy and security concerns, making oil dependence and energy diversity active topics of state and national energy policy discussion (Kerry, 2002; McNulty, 2001).

8. Basis for scenario modeling

The scenario modeling exercise draws on the context of the scenario narratives, identifies a set of plausible policies and choices for each scenario, and examines the implications of each scenario for future energy consumption, composition of electricity generation, energy diversity, and greenhouse gas emissions through 2035. The BAU scenario serves as a reference scenario and point of comparison for the alternative scenarios and is based on assumptions reported in state planning literature. The alternative scenarios are based around sets of plausible policies, choices, and patterns that are coherent with the context of each scenario narrative.

The scenario elements are modeled using explicit assumptions of how energy, technology, and activity parameters change over time. This approach links contextual narratives to specific physical changes in use patterns, technology attributes, and demographic drivers. Economic factors (e.g. costs of alternative technologies, fuel prices, etc.) are incorporated indirectly through the choice of market penetrations for different technologies. The long time horizon of the scenarios is assumed to be sufficient for technologies that are not now cost competitive to become competitive through technological change, research and development, market pull programs, and other public policies. A detailed treatment of background assumptions and justification for the scenario elements is summarized in Appendix A. We do not estimate the costs of the alternative scenarios, a complex task that we leave for future work.

Table 4 presents modeled elements of the BAU scenario. Table 5 reviews the modeled elements of the alternative scenarios. It is important to recognize that the scenarios are not intended to incorporate every activity that might be possible under each scenario. Rather, the scenario analysis associates a small, specific set of activities to each scenario that are consistent with the narratives and provide an opportunity to explore critical uncertainties in California's future energy pathway.[6]

9. The analytical framework

The scenario modeling is founded on a detailed sectoral database of historic and forecast data for California[7] and integrated with the scenario-based modeling platform, Long Range Energy Alternative

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[6] While a small set of options are considered in this study, there is a significant opportunity for additional scenario analysis efforts to develop more comprehensive scenarios that would include the results of studies that have appeared since the California crisis reached its peak. For example, a report sponsored by the Energy Foundation and the Hewlett Foundation that appeared in late 2002 (after the main scenario analysis for this study was completed) contains many examples of cost effective efficiency technologies, including savings potential and cost estimates for options in the residential, commercial and industrial sectors that could be incorporated into a more comprehensive scenario exercise (Rufo and Coito, 2002).

[7] The sources used to develop the California Energy Database are referenced in Appendix B.

Table 4
Overview of business-as-usual scenario elements

	Business-as-usual
Logic	*Post-deregulation world characterized by crisis-inspired growth of electricity sector, continuous trends in other sectors, and existing technologies and policies*
Residential	Increasing population and households, 1.3%/yr[a] Steady economic growth, raising personal incomes Household computers and printer use reaches levels of TVs and VCRs, by 2035 Refrigerator sizes increase, 0.2%/yr Greater use of household air conditioning, 70% by 2035 Natural gas efficiencies improve for space and water heating technologies, 1.7%/yr
Transportation	Increasing population, 1.3%/yr Vehicles driven with same number of passengers per vehicle (ex. 1.6 people/car) People drive more miles per year, 0.4%/yr Increasing popularity of light duty trucks/SUVs relative to cars, reaching 44% by 2035 Modest penetration of hybrid and electric cars and light duty trucks, 5% by 2035 Modest penetration of hybrid, electric, and natural gas buses, 13% by 2035 Constant passenger vehicle average fuel economy for gas and diesel vehicles Air travel per person increases, 1.7%/yr Energy intensity of air travel decreases, −0.7%/yr Freight activity per person increases, 0.4%/yr Constant composition of freight activity, % rail, road, water Constant freight vehicle fuel economies
Commercial	Increasing commercial floorspace, 1.5%/yr Constant relative composition of building types Saturations of commercial end uses remain the same Electricity intensities increase overall, 2.0%/yr Natural gas intensities decrease overall, 1.1%/yr
Industrial	Increasing industrial value of shipments, 4.0%/yr Industrial sub-sector shares of total industrial value of shipments change slightly Electricity and natural gas intensities decrease overall, variable %
Electricity generation	Natural gas is significant fraction of capacity additions, 81% of additions 2000–2035[b] Renewables are moderate fraction of capacity additions, 19% of additions 2000–2035[c] Imports make up capacity shortfalls above natural gas and renewables additions Minimum import level set to current level of fixed-coal generation imports (30 TWh)[d,e]

[a] All annual percentages refer to an average annual rate of change over the scenario horizon of 2000–2035.

[b] BAU scenario uses CEC's "most likely" and "baseline" scenario categories to derive capacity additions (CEC, 2002b, Table I-2 and II-2-1).

[c] Renewables is used here to refer to renewable energy based electricity generation and does not include large hydroelectric generation. In these analyses, this category includes primarily wind, geothermal, and biomass, and to a lesser extent landfill gas, digestor gas, municipal solid waste, small hydro, and solar.

[d] Minimum import level for the BAU is equal to the average level of imports from utility-owned, out-of-state coal generation with exclusive sales to California between 1998 and 2000 (CEC, 2002a).

[e] All other BAU elements are based on assumptions and expectations derived directly or through interpretation of state data and reports that are summarized in Appendix B (Table 14).

Planning System (LEAP),[8] to create multi-sector end-use model of energy supply and demand in California. The California LEAP end-use model is used to characterize the composition and structure of energy, fuel use, and greenhouse gas emissions for each scenario between 2000 and 2035. The structure and composition of the base year, 2000, is founded on existing state-level information and is consistent with overall fuel balance and technology and end-use estimates of the magnitude and composition of energy and fuel consumption. The base year ensures a common starting point for the scenarios and grounds the analysis in the reality of the state's existing energy system.

The California energy scenario model considers five demand sectors: transportation, commercial, industrial, and other, and one fuel transformation sector: electricity generation. Primary fuels are used directly by demand

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[8] LEAP, is an accounting and scenario-based energy-modeling platform developed by Stockholm Environmental Institute Boston Center for energy, environment, and emissions applications. http://www.seib.org/leap.

Table 5
Overview of alternative scenario elements[a]

	Split Public	Golden State	Patriotic Energy
Logic	*Consumers and communities champion clean energy*	*Integrated planning emerges from earlier crisis*	*Uncertain international order inspires drive for greater energy independence*
Agents of change	Household and consumer behavior, local organizing, municipal activities	System planning, state energy policy, dialogue and consensus building, priority to state management of resources	International security concerns, government-private sector research and development, assertive national policy and planning
Residential	Activity level of 50% of public by 2035 Solar water heaters Efficient lighting Solar systems, 1 KW Line drying, 25%	Activity level of 30% of public by 2035 Solar water heaters Efficient lighting Solar systems, 1 KW Line drying, 15%	Activity level same as Split Public, motivated by patriotic interest in decreasing US fossil fuel dependence
Transport	Light trucks/SUV fraction of passenger vehicles decreases from 37% to 25% by 2035 Penetration of alternative people-moving vehicles: Hybrid and electric cars and light trucks, average penetrations 50% of stock by 2035 Hybrid, electric, and natural gas bus combined penetrations, 50% of stock by 2035 No change in US passenger and freight vehicle fuel economy standards	Light trucks/SUV fraction of passenger vehicles decreases from 37% to 30% by 2035 Penetration of alternative people-moving vehicles: Hybrid and electric cars and light trucks average penetrations, 30% of stock by 2035 Hybrid, electric, and natural gas bus combined penetrations, 30% of stock by 2035 No change in US passenger and freight vehicle fuel economy standards	Light trucks/SUV fraction of passenger vehicles decreases from 37% to 20% by 2035 Complete phase out of full-gas/diesel passenger vehicles by 2035: Hybrid and electric, 60% of stock of passenger vehicles by 2020 Direct-hydrogen fuel cell, 75% of stock of passenger vehicles by 2035 Increased US freight fuel economy standards
Commercial	Municipal initiatives lead to 600 MW wind and 1200 MW solar by 2035	Municipal initiatives lead to 360 MW wind and 720 MW solar by 2035	Activity as Split Public, motivated by patriotic interest in decreasing US fuel dependence
Industrial	Same as BAU	Same as BAU	Same as BAU
Electricity generation	Natural gas provides 81% of new capacity additions Renewable energy sources provides 19% of new capacity additions, primarily as wind, geothermal, and biomass Imports reduced by >8%	State Renewable Portfolio Standard of 20% by 2017 Renewable sources provide 48% of new capacity additions, primarily as wind, geothermal, and biomass Imports reduced by > 40%	National Renewable Portfolio Standard of 20% by 2020 Renewable sources provide 54% of new capacity additions, primarily as wind, geothermal, and biomass Imports reduced by >40%

[a] A detailed explanation of key assumptions and justification for the scenario elements is summarized in Appendix A (Table 13).

sectors and to generate electricity. The level of electricity consumption by the demand sectors determines the overall quantity of electricity generated each year. The composition of electricity generation is determined using explicitly assigned technology categories, attributes, merit order, system load curve, and import/export specifications.

Each individual supply and demand sector is disaggregated to the level of end uses and technologies which consume, generate, or transform fuels (Table 6). The model structure is influenced by the type of state-level data that was available for each sector. Technologies and/or end uses are characterized by a set of specific parameters, including: market saturation, fuel consumption, energy efficiency, energy intensity, and demographic and/or activity drivers. The modeling framework accommodates policies and changes associated with the scenarios and are directed at specific technologies and end uses. The energy scenarios are modeled by combined changes in activity, structure, and energy intensities over time.

Table 6
Composition of modeling framework: supply sectors, demand sectors, primary fuels

Sector/fuels	Categories	Sub-categories	Activity parameters
Residential	6 end-use categories (e.g., *air conditioning*)	86 technologies (e.g., *forced gas heating*)	Households (# hh) Saturations (%) Unit energy consumption (E/yr)
Transportation	3 categories (*passenger, air, freight*) 9 end-use categories (e.g., *light trucks*)	38 technologies (e.g., *hybrid gasoline-electric cars*)	Population Passenger miles traveled Freight miles traveled Air miles traveled Share of miles traveled (%)
Commercial	11 building types (e.g., *food stores*)	10 end-use categories (e.g., *interior lighting*)	Floorspace (ft^2) Shares of floorspace (%) Saturations (%) Energy intensities (E/ft^2)
Industrial	31 categories (e.g., *printing and publishing*)	5 fuel categories (e.g., *natural gas*)	Value of shipments ($) Category shares (%) Energy intensities (E/$)
Other	3 categories (e.g., *street lights*)	2 fuel categories (e.g., *electricity*)	Gross state product ($) Population Energy intensities (E/$; E/person)
Electricity generation	18 technologies (e.g., *steam turbine*)	9 fuel categories (e.g., *biomass*)	System load curve Capacity (MW) Base year output Maximum capacity factor Efficiency (%) Fuel shares (%) Merit order (1st–5th) Planning reserve margin (%) Transmission and distribution losses (%)
Primary fuels	Natural gas, Oil products, Coal, Nuclear, Hydro, Geothermal, Biomass, Wind, Solar		

10. Energy and greenhouse gas emissions calculations

Energy consumption for each demand sector is calculated using a set of equations built around technology energy intensities, saturation data, and activity drivers within each sector. Energy consumption in the residential sector is calculated as the product of the total number of households, the saturation of the end use in residential households, the technology share of the end use, and the unit energy consumption of the given technology. Total energy consumption is the sum of individual consumption of each of the different end-use technology categories. Transportation consumption is calculated from the total passenger, freight, and air miles traveled, technology shares of transportation activity, and technology fuel economies. Commercial consumption is based on the total commercial floorspace, the share of commercial floorspace of each building type, the saturations of end uses within each building type, and the fuel intensities on a square foot basis for each end use. The model calculations of industrial consumption are based on the total industrial value of shipments, sub-sector shares of total industrial value of shipments, and fuel intensities per shipping value for each sub-sector. The other demand sector is comprised of agriculture, streetlights, and transportation, communications, and utilities. Similarly, consumption is calculated from the activity parameter and fuel intensities per unit of activity.

Electricity generation is calculated to meet electricity demand requirements of the individual demand sectors. The electricity generation module uses explicitly specified technology categories and attributes as well as a specified merit order, annual system load curve, and import and export requirements to meet the total annual electricity demand resulting from each set of scenario assumptions. The base year composition of generation technologies and generation output of California's power sector is built from existing state-level power plant data. For these analyses, electricity losses from transmission and distribution were assumed to be 10%, and capacity additions were based on an optimal reserve margin of 15%. New capacity additions are added either exogenously or endogenously to the generation sector.

Exogenous capacity additions are planned additions with a specific quantity and type of capacity added at a specific time in the future. Endogenous capacity additions are specific technologies that are built as needed to meet the electricity consumption requirements as specified by the demand sectors.

The greenhouse gas emissions associated with fuel consumption in California were estimated using average emissions factors for each sector and fuel type, according to IPCC guidelines for national greenhouse gas inventories and 1996 Tier 1 average emissions factors. The Technology and Environment Database (TED) within the LEAP modeling platform directly links each technology within the supply and demand structure to an average emissions factor based on its sector and fuel use. Total greenhouse gas emissions were calculated in terms of global warming potential in units of carbon dioxide equivalents.

11. Quantitative modeling results

The quantitative scenario modeling results explore the implications of each scenario for future consumption of energy, composition of electricity generation, energy diversity, and greenhouse gas emissions. It is important to recognize that our discussion does not aim to advocate any particular scenario or make any distinct claims about how the future will actually unfold. Rather, the results demonstrate a subset of the many activities and outcomes that are possible. We acknowledge that there are considerable uncertainties inherent in this type of analysis (particularly for scenario exercises extending over several decades), and the results must be considered in this context. These analyses represent an exercise that illustrates possibilities for the future in a way that strives to be quantitative and transparent. These scenario results aim to catalyze continued discussion of future choices and decisions that will shape California's future.

12. Combined energy consumption of demand sectors

The combined final energy consumption of California's residential, commercial, industrial, and other demand sectors is expected to increase steadily over the next decades under BAU conditions. The composition of state energy consumption reveals that the transportation sector makes up more than 50% of energy consumption in 2000 and continues to increase in absolute and relative terms under BAU conditions through 2035 (Fig. 4). The remaining energy consumption is split between industry, residential, commercial, and other demand sectors, in decreasing order.

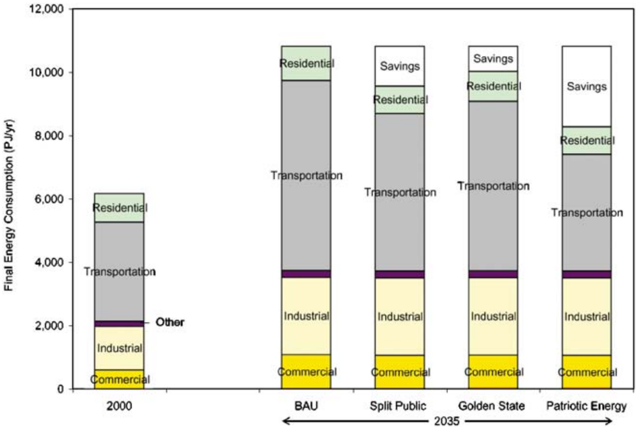

Fig. 4. Combined energy consumption of demand sectors in 2000 and for each scenario in 2035 in petajoules (10^{15} J)/yr. Energy savings of the alternative scenarios relative to BAU are also indicated for 2035. Note that combined energy consumption corresponds to final energy consumed within the demand sectors and therefore implicitly includes electricity generation including imports from outside of the state.

Each of the alternative scenarios demonstrates energy savings compared to BAU in 2035, with Patriotic Energy showing the greatest energy savings, followed by Split Public and then Golden State. The largest component of these savings is derived from the transportation sector with residential and commercial sector activity savings making up smaller shares. Alternative scenario activities in the industrial and other demand sector activities are not developed in these scenarios and represent an opportunity for future work.

The absolute and relative size of transportation energy consumption brings to light the dominant role the transportation sector plays in defining California's overall energy pathway. Even under conditions of active transportation reform, the overall potential for state energy savings is constrained by increasing per capita driving activity, growing population, and other forms of non-road transportation such as shipping and air travel. It is perhaps surprising to note that even under the conditions of 50% and 30% penetration of hybrid and electric passenger vehicles by 2035 in Split Public and Golden State, transportation energy consumption continues to increase. These scenarios point to the critical importance of transportation policies and activities in California for managing levels of absolute energy consumption in the face of continued trends of increasing population and driving activity. These results show that transportation is California's greatest energy challenge in terms of overall energy consumption.

Residential and commercial savings are also achieved in the alternative scenarios through energy efficiency and renewable energy activities. In our analysis, small-scale and distributed renewable energy-based electricity generation by households and commercial sectors are reported as demand offsets at the residential and commercial levels rather than within the state-level

Table 7
Combined energy consumption: rates of growth, relative savings, and composition

	Base year 2000	BAU 2035	Split Public 2035	Golden State 2035	Patriotic Energy 2035
Energy consumption[a] (PJ)	6200	10,800	9600	10,000	8300
Growth rate (avg. annual % 2000–2035)	—	1.6%	1.3%	1.4%	0.80%
Scenario savings					
Savings (PJ) in 2035	—	—	1200	800	2500
Savings vs. BAU (%) in 2035	—	—	11%	7%	23%
Consumption share					
Residential	15%	10%	9%	9%	11%
Transportation	51%	55%	52%	53%	44%
Commercial	10%	10%	11%	11%	13%
Industrial	22%	23%	26%	24%	30%
Other	3%	2%	2%	2%	3%
Total[b]	100%	100%	100%	100%	100%

[a] Combined energy consumption corresponds to final energy consumed within the demand sectors; electricity generation and electricity imports are represented within the consumption of each demand sector.

[b] Consumption shares may not sum to 100% due to rounding.

electricity generation sector. Of the residential activities, adoption of solar water heaters has the greatest impact, representing more than 65% of total residential energy savings in 2035, followed by solar home systems comprising 19% of savings, efficient lighting 11%, and greater clothesline use 5%. Even an activity as mundane as use of clothes line drying for a quarter of household activity has a measurable effect on residential energy consumption, one reminder that wide-spread, small actions in a populous state like California can have measurable impacts (Table 7).

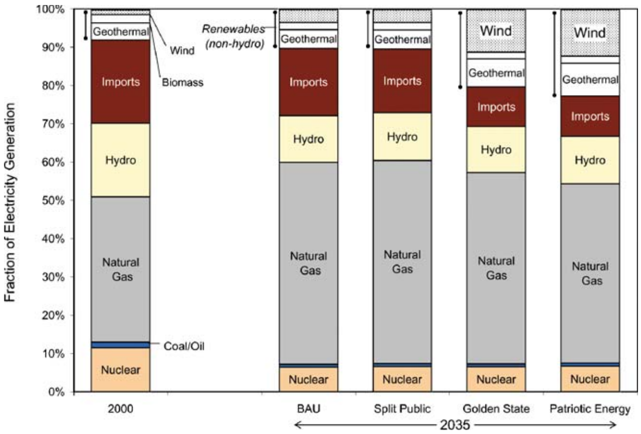

Fig. 5. Composition of electricity generation by fuel source in 2000 and each scenario in 2035. Natural gas generation is expected to significantly increase in the BAU and Split Public scenarios. Golden State and Patriotic Energy reduce electricity imports and expand renewable energy-based generation to continue to meet 20% targets primarily from wind, geothermal, and biomass (biomass category also includes small amounts of digestor-gas, landfill gas, and municipal solid waste).

13. Electricity generation

The form of California's future electricity sector is highly uncertain, and each scenario explores different configurations of key variables. The BAU scenario explores post-energy crisis expectations leading to a significant fraction of new capacity being derived from natural gas. Split Public mirrors the electricity sector of the BAU scenario; the scenario's local and individual activities are assumed to be unable to exert influence over state-level private sector investment and state electricity planning. Golden State explores conditions of assertive state renewable energy policy. Patriotic Energy reflects a national drive to develop non-fossil fuel energy resources. All of the future scenarios show increases in natural gas-based electricity generation. Increases are most dramatic for the BAU and Split Public scenarios. Golden State and Patriotic Energy incorporate growing shares of electricity generation from renewable energy sources and a reduction of imports.

In 2000, almost 40% of the electricity generated to serve California consumption was derived from natural gas (Fig. 5). Out-of-state electricity imports made up the next largest share, followed by hydro, nuclear, renewables,[9] and coal/oil. The share of natural gas generation increases in BAU and Split Public to approximately 53% of generation. In contrast, Golden State and Patriotic Energy show increased shares of renewable energy generation, captured primarily as wind, geothermal, and biomass[10] catalyzed by state or national RPS policies implemented early in the scenario timescales. Golden State implements and exceeds a state RPS; Patriotic

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[9] Renewables refers to renewable energy based electricity generation and does not include large hydroelectric generation.

[10] Biomass also includes small amounts of digestor-gas, landfill gas, and municipal solid waste.

Table 8
Composition of electricity generation in the base year in 2000 and scenarios in 2035

	Base year 2000	BAU 2035	Split Public 2035	Golden State 2035	Patriotic Energy 2035
Generation (TWh)	286	534	520	522	509
Generation shares (%)					
Natural Gas	38%	53%	53%	50%	47%
Renewable (*non-hydro*)	8%	10%	11%	20%	23%
Hydro	19%	12%	13%	12%	12%
Nuclear	11%	6%	7%	7%	7%
Coal/oil	1%	1%	1%	1%	1%
Imports	22%	18%	17%	10%	11%
Total[a]	100%	100%	100%	100%	100%

[a] Consumption shares may not sum to 100% due to rounding.

Energy also exceeds a national RPS making California a leader in renewable-energy based electricity generation.

The role of electricity imports is an important variable in California's future power sector. Fig. 5 shows that in 2000 electricity imports accounted for slightly more than 20% of generation. Between 1998 and 2000, the fraction of imports relative to total electricity generation serving California electricity needs has ranged between 22% and 30% (CEC, 2002a). In this analysis, the dispatch methodology of the scenario modeling platform examines the annual magnitude and composition of power generation and imports so as to meet a specified annual system electricity load curve. However, our analyses do not examine instantaneous cost and demand patterns, which would be required for a more detailed analysis of import conditions.

The BAU scenario sets a minimum level of imports equivalent to the current level of fixed-coal electricity imports.[11] In this case, imports in addition to this minimum level occur only when the state cannot meet electricity demand with in-state generation. The BAU approach explores the potential for electricity generated from new natural gas capacity to decrease overall import levels, suggesting that the level of proposed new construction in the post-energy crisis conditions has the potential to dramatically change the context for imports and for possible new renewable energy capacity particularly in the near term. The way that conditions and trade-offs for imports and capacity additions will actually play out is uncertain, however they clearly indicate the importance of examining system-wide effects inherent in the proposed capacity additions emerging from the post-energy crisis context. Split Public reflects the same power sector and import assumptions as the BAU scenario with a slightly lower overall level of generation due to electricity conservation and self-generation in residential and commercial sectors.

Golden State and Patriotic Energy represent a different approach to future power sector development. Both scenarios reduce overall electricity import level. This assumption is consistent with the logic that Golden State's integrated state planning places high value on development of a diversified generation system that can be managed by the state. Increases in renewable energy generation and reductions in imports become important planning criteria in Golden State and a part of the state's strategy for meeting and exceeding its RPS policy. Under these conditions, imports decrease significantly from 20% in 2000 to 10% in 2035. Patriotic Energy also demonstrates a decrease in imports. In this scenario, renewable-derived electricity from states rich in renewable resources becomes an important part of a national strategy to reduce the fossil fuel dependence of the nation's electricity-sector and free up available fossil fuels for high value uses, such as heating and industrial processes. California develops its renewable-based generation primarily in the form of wind, geothermal, and biomass (Table 8).

14. Implications for energy diversity

Energy diversity plays a role in supply security, financial risk, energy planning, and the environment. In California, increasing energy diversity is also linked to decreasing relative fossil fuel dependence. With the large fraction of state primary energy consumption attributed to oil and natural gas, and the state's share of coal consumption unlikely to increase, energy consumption will only become more diverse if a greater proportion of state energy consumption is made up of non-fossil fuels.[12] The analysis of the energy diversity of each scenario provides one indication of the extent to

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[11] Fixed coal imports serving California have averaged around 30,000 GWh or 12% of demand between 1998 and 2000 (CEC, 2002a).

[12] It is important to note that the link between energy diversity and decreasing reliance on fossil fuels is not true in every energy system; it is only because of the particular circumstances of California with already large oil and natural gas fuel shares and limited potential growth of coal fuel shares that this claim can be made.

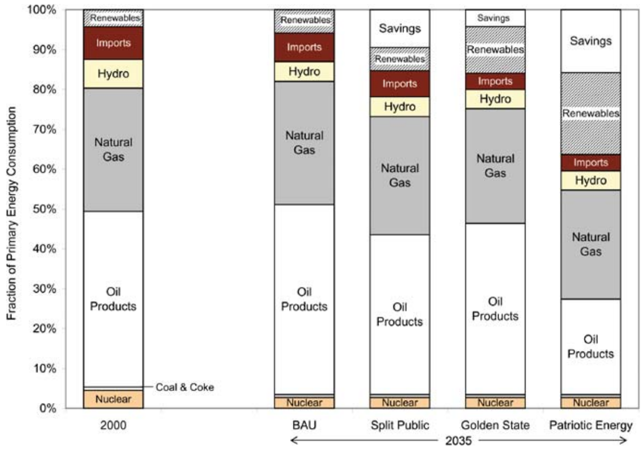

Fig. 6. Category shares of primary energy consumption in 2000 and for each scenario in 2035. Primary fuels as well as primary energy associated with electricity imports and energy savings (relative to the BAU scenario in 2035) are included as separate category shares.

which the scenarios present alternatives to BAU futures dominated by fossil fuel use.

The composition of primary energy consumption is used as the primary basis for assessing the energy diversity of California's energy system. Fig. 6 shows the largest fuel fractions of overall primary energy consumption to be attributed to oil and natural gas. Fossil fuels accounted for 75% of primary energy consumption in 2000, and their share increases under BAU conditions to nearly 80% by 2035 (Table 9). The alternative scenarios demonstrate a decrease in the fraction of fossil fuels, with Split Public and Golden State showing decreases in fossil fuel shares to 71% and 73%, respectively, and Patriotic Energy showing a dramatic reduction to 52%. Demonstrating the dynamic of decreasing fossil fuel shares, energy diversity increases in Split Public, Golden State, and Patriotic Energy. In the BAU scenario, the opposite is true; fossil fuel shares increase, and energy diversity decreases between 2000 and 2035.

A simple index for diversity, based on the classic Herfindhal measure of market concentration, provides a method to quantitatively examine the relationship between category shares and energy diversity (Neff, 1997). The diversity index is calculated as

$$H = 1/\sum x_i^2,$$

where x_i is the category fraction from source "i". Values of H range between 1 and the total number of categories, and the higher the value of H, the greater the energy diversity. This analysis uses eight categories to calculate energy diversity, making the maximum possible value of H to be eight and minimum value to be one.[13] The eight categories used in the calculation include: oil products, natural gas, coal/coke, hydropower, nuclear, renewables,[14] electricity imports, and energy savings. The argument for creating a category for electricity imports is the generally different risk profiles of electricity imports and in-state electricity generation. Creating a separate category for energy savings makes it possible to incorporate both supply and demand opportunities for increasing energy diversity, recognizing that fossil fuel consumption can be displaced by supply shifts toward non-fossil fuels like renewables or demand changes to achieve energy savings through energy efficiency or conservation.

The most notable result of these analyses is the loss of energy diversity between 2000 and 2035 under BAU conditions evidenced by the decreasing index values (Table 9). Significant increases in natural gas power generation and dramatic increases in transportation and oil consumption are the primary factors responsible for the loss of energy diversity. In contrast, all three alternative scenarios show gains in energy diversity compared to the BAU scenario. The most diverse scenario is Patriotic Energy, followed by Split Public, and then Golden State. Energy diversity gains in Golden State are achieved through diversification of the power sector and to a lesser extent through transportation and residential activities. Split Public achieves greater energy diversity than Golden State largely through energy savings associated with greater activity in residential energy efficiency, renewable-based power generation, and hybrid and electric vehicle use. Patriotic Energy is the most diverse scenario as a result of sweeping transportation changes, diversification of the power sector, and residential and commercial efficiency and renewable energy activities.

These results show that the key dynamic of increasing energy diversity is to reduce natural gas and oil dependence through energy savings and renewable energy activities. Transportation and electricity generation, with their direct association to oil and natural gas consumption, are critical sites for diversity activities. Households, community, and industry also have a role to play. An integrated approach combining technology, policy, and individual choices is needed if the energy diversity of the state is to increase over the next decades.

15. Implications for greenhouse gas emissions

With a large population, driving-intensive lifestyle, and high level of economic activity, California accounts for a significant level of greenhouse gas emissions. The average Californian is responsible for about three times

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[13] Maximum diversity is achieved when all eight categories have equal shares, or $H = 8 = (8*(1/8)^2)^{-1}$. Minimum diversity corresponds to conditions when one category has a 100% share, thus $H = 1 = (1^2)^{-1}$.

[14] Renewables include wind, solar, geothermal, small-hydro, biomass, digestor gas, landfill gas, municipal solid waste, and hydrogen.

Table 9
Primary energy consumption and scenario diversity index

	Base year 2000	BAU 2035	Split Public 2035	Golden State 2035	Patriotic Energy 2035
Diversity index, H	3.27	2.99	3.72	3.48	4.90
Primary energy consumption (PJ)[a]	8241	14,243	12,888	13,641	11,993
Electricity imports[b]	8%	7%	7%	4%	4%
Oil products	44%	48%	40%	43%	24%
Coal and coke	1%	1%	1%	1%	1%
Natural gas	31%	31%	30%	29%	27%
Hydro	7%	5%	5%	5%	5%
Renewables	4%	6%	6%	12%	21%
Nuclear	4%	3%	3%	3%	3%
Savings vs. BAU (2035)	—	—	10%	4%	16%
Total[c]	100%	100%	100%	100%	100%

[a] Total primary energy accounts for direct consumption of primary fuels by demand sectors and electricity generation (i.e. it accounts for natural gas used to generate electricity, not electricity itself).

[b] The primary energy consumption associated with electricity imports is estimated assuming 33% conversion efficiency of primary energy to electricity that is then imported into California from other states.

[c] Consumption shares may not sum to 100% due to rounding.

the carbon dioxide emissions of the average world citizen[15] (Fig. 7). If California were a country, it would rank approximately 15th in terms of total carbon dioxide emissions. Including out-of-state fuel generation in the form of electricity imports, a measurable component of which are derived from coal, California would assume an even greater share of global emissions.

Reducing absolute and per capita emissions will require alternatives to current trends. To explore opportunities for change, this analysis investigates the greenhouse gas implications of the scenarios and considers their potential for mitigating emissions. Our emissions calculations are based on 1996 IPCC tier one emissions factors and fuel consumption in each sector. We first focus on in-state emissions, and then treat the emissions from imported electricity in a sensitivity analysis (emissions from imports are subject to a substantial amount of uncertainty).

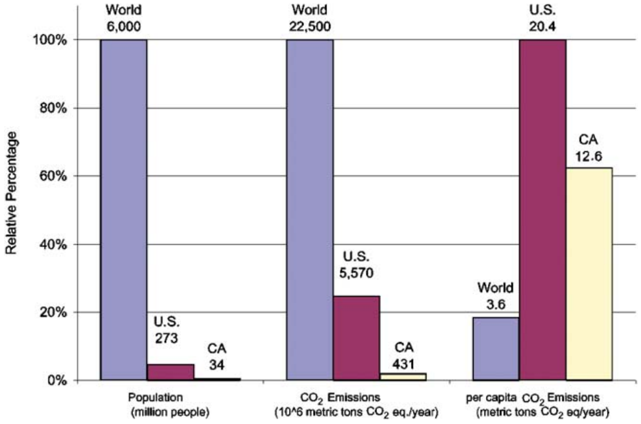

Fig. 7. Greenhouse gas emissions in California, the US, and the world, on a gross and per capita basis in 1999. California emissions estimates include only in-state emissions. Accounting for electricity imports from outside of the state is estimated to increase gross state emissions on the order of 7–14% in 2000. Sources include (CEC, 2001f; EIA, 2001f, g; US Census, 1999c).

Fig. 8 shows the magnitude and composition of in-state greenhouse gas emissions by sector in 2000 and each scenario in 2035. In-state greenhouse gas emissions in 2000 are estimated to be 431 million metric tons of carbon dioxide equivalents. This value is estimated to increase more than 81% by 2035 in the BAU scenario. Split Public, Golden State, and Patriotic Energy show lower rates of emissions increases. Comparing scenario emissions to 1990 levels provides a reference to Kyoto Protocol targets. Using a California Energy Commission estimate of 1990 gross emissions of 425 million metric tons carbon dioxide equivalents (CEC, 2002f), BAU, Split Public, Golden State, and Patriotic Energy emissions in 2035 are 84%, 59%, 66%, and 12% above 1990 levels (Table 10). These results illustrate the sensitivities of the small set of activities incorporated into each scenario for emissions reductions; these results should not be viewed as indicative of the full potential for greenhouse gas mitigation in the state. Comprehensive mitigation scenarios would require a much more detailed set of modeled mitigation activities than are incorporated into these scenarios as well as an analysis of the combustion and non-combustion related emissions and sinks.

Looking at sector shares, greenhouse gas emissions in California are dominated by transportation. In 2000, the transportation sector accounts for more than 50% of emissions (Table 11). Transportation emissions continue

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[15] This estimate is based on 1999 values presented in Fig. 7.

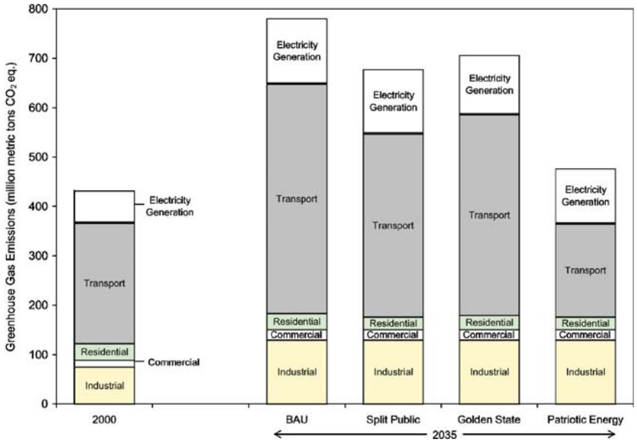

Fig. 8. In-state greenhouse gas emissions by sector in 2000 and scenario in 2035 in million metric tons of carbon dioxide equivalents. In-state emissions are estimated to increase more than 81% by 2035 in the BAU scenario. Split Public, Golden State, and Patriotic Energy demonstrate more moderate increases of 57%, 64%, and 10%. Accounting for electricity imports from outside of the state is estimated to increase total state emissions on the order of 7–14% in 2000 and 4–12% in 2035. Note these scenarios do not represent the complete suite of multi-sector emissions mitigation activities that might be possible in California's future energy system. As a result, the sensitivities of emissions reductions relative to the BAU scenario are the most meaningful dimension, rather than absolute magnitudes of scenario emissions profiles.

Table 10
Total in-state greenhouse gas emissions (million metric tons CO_2 equivalents)

	1990[a]	2000	2035	% Change 2000–2035	% Change 1990–2035
BAU	425	431	780	81	84
Split Public			677	57	59
Golden State			706	64	66
Patriotic Energy			476	10	12

[a] *Source*: (CEC (2002f).

to increase in the BAU, Split Public, and Golden State scenarios. Only the Patriotic Energy scenario shows a decrease in transportation emissions. It is interesting to note that even the 50% and 30% penetration of hybrid and electric passenger vehicles in Split Public and Golden State are not sufficient to offset increasing emissions due to population growth, freight growth, and increasing driving activity. Only in Patriotic Energy, where fossil fuel powered cars and light duty trucks are fully displaced by fuel cells, hybrid, and electric vehicles and aggressive freight fuel economy standards are adopted do transportation emissions decrease in absolute and relative terms. These results suggest that transportation needs the greatest attention if the state is to mitigate its greenhouse gas emissions. An important step in this direction is the passage into law of a much debated bill in July 2002 requiring the California Air Resources Board to adopt regulations to reduce the emissions of greenhouse gases by motor vehicles (California Legislative Counsel, 2002, Assembly Bill 1493). This new law promises to create a base of authority and information that will be needed to begin to address the emissions from cars and trucks in California.

Another important result is the potential for decreasing emissions associated with diversification of the state's power sector to incorporate a greater share of renewable energy. In the BAU scenario, in-state emissions from electricity generation in 2035 increase by 108% from 2000 levels as a result of increasing electricity demand and increasing shares of natural-gas generation. Golden State has a more diversified generation sector and demonstrates an 87% increase in emissions compared to 2000. This difference is primarily attributed to a decrease in the expected natural gas capacity additions in Golden State as a result of electricity savings in residential and commercial sectors and an increase in renewable energy generation to make up this difference in capacity.

Imports from outside the state are an important and challenging dimension of California greenhouse gas emissions accounting. Between 1998 and 2000, California imported between 22% and 30% of its electricity requirements; 10–18% of state electricity demand was served with imports from the Pacific Northwest and southwest and 10–12% from investor-owned, out of state coal generation plants that supply electricity exclusively to California (CEC, 2002a). These emissions are a critical part of accurate accounting of California's inventory of greenhouse gas emissions. In particular, imports from out-of-state coal-fired power plants serving California demand represent a measurable component of emissions associated with California's actual energy services.

To make a first level approximation of greenhouse gas emissions for electricity imports, we use a set of simple assumptions to estimate the high and low emissions limits which would bracket the actual value of import emissions. The low emissions limit assumes conditions where the only imports emissions come from fixed-coal generation. The level of fixed-coal imports is assumed to remain constant at approximately 2000 levels throughout the scenarios (30,000 GWh). The low emissions limit assumes that the 10–18% of electricity requirements that are imported from the Pacific Northwest and Southwest are non-emitting, and the rest are from coal-fired power plants. The high emissions limit assumes that all imports are from coal-fired power plants. Import levels vary depending on the scenario import assumptions.

Based on low and high emissions limit calculations, electricity imports would increase electricity sector emissions estimates in the range of 48–99% in 2000 and 23–72% in the BAU scenario in 2035 (Table 12).

Table 11
In-state greenhouse gas emissions and change by sector, 2000 and 2035 (million metric tons CO_2 equivalents)

	Base year 2000	BAU 2035	Split Public 2035	Golden State 2035	Patriotic Energy 2035
In-state emissions	431	780	677	706	476
Sector emissions					
Residential	33	33	26	29	26
Transportation	244	464	370	406	188
Commercial	14	21	21	21	21
Industry	74	129	129	129	129
Other	2	3	3	3	3
Electricity generation[a]	63	131	128	118	110
% Change 2000–2035					
Residential		−1%	−23%	−13%	−22%
Transportation		90%	52%	66%	−23%
Commercial		49%	49%	49%	49%
Industry		73%	73%	73%	73%
Other		17%	17%	17%	17%
Electricity generation		108%	104%	87%	75%
Total		81%	57%	64%	10%

[a] Electricity generation emissions are only for in-state emissions and do not include emissions associated with imported electricity. Accounting for electricity imports from outside of the state is estimated to increase total state emissions on the order of 7–14% in 2000 and 4–12% in 2035 (see Table 12).

Table 12
Greenhouse gas emission estimates for in-state electricity generation and electricity imports (million metric tons CO_2 equivalents)

	Base year 2000	BAU 2035	Split Public 2035	Golden State 2035	Patriotic Energy 2035
In-state electricity generation emissions	63	131	128	118	110
Electricity imports emissions estimate[a]					
Low emissions limit[b]	30	30	30	30	30
% of in-state electricity emissions	*48%*	*23%*	*23%*	*25%*	*27%*
High emissions limit[c]	62	94	86	54	54
% of in-state electricity emissions	*99%*	*72%*	*67%*	*46%*	*49%*
Estimated increase in total state emissions from electricity imports accounting[d]					
Base year, 2000	7–14%				
Scenarios, 2035	4–12%				

[a] Calculations use electricity generation emissions factor for coal-derived electricity of 92.644 metric tons CO_2/TJ coal consumed and 33% conversion efficiency for coal-fired power plants.

[b] Low emissions limit assumes the first 30,000 GWh of electricity imports come from coal derived electricity (equivalent to year 2000 fixed-coal imports), any additional imports assumed non-emitting.

[c] High emissions limit assumes all electricity imports are derived from coal-fired power plants, actual emissions associated with imports would fall somewhere between the low and high emissions limit.

[d] Values represent the increase in total state emissions that would result from including the range of low and high emissions estimates for electricity imports in 2000 and all of the scenarios in 2035.

Recognizing that non-fixed imports from the Pacific Northwest and Southwest come from hydro, natural gas, coal, and other sources, the actual emissions contribution of imports would be higher than the low limit. Accounting for electricity imports from outside of the state is estimated to increase gross state emissions on the order of 7–14% in 2000 and 4–12% in 2035 (see Table 12). These values represent the increase in total state emissions that would result from including the range of low and high emissions estimates for electricity imports in 2000 and all of the scenarios in 2035.

These results emphasize the importance of comprehensive accounting of state greenhouse gas emissions. Particular attention needs to be paid to transportation, electricity generation, and electricity imports. Mitigation of state emissions will require systematic information, monitoring, and policy incentives. Climate change promises to be one of the most profound challenges to California's energy pathway. These analyses represent a first step toward examining mitigation options for the future.

16. Lessons, opportunities, and policy implications

California energy scenarios are a visioning tool that provides an opportunity to explore the context of current choices and priorities for the future. This paper concludes by presenting a summary of important policy lessons, opportunities, and policy implications that emerge from the scenario analysis. These ideas synthesize scenario findings and represent a call for active and critical examination of the context and implications of future choices in California.

1. *California is on a fossil fuel pathway*. California's BAU pathway reveals decreasing energy diversity and increasing fossil fuel dependence. Currently, fossil fuels comprise more than 75% of primary energy demand. Expectations of increasing numbers of vehicles, greater driving activity, and construction of natural gas power plants would take California down a pathway toward even greater reliance on fossil fuels. Scenario analysis shows that energy savings, renewable energy, and transportation activities provide critical opportunities for achieving more diverse energy pathways.

2. *Transportation is the major energy consumer and emitter of greenhouse gases in the state*. Transportation accounts for more than half of state energy consumption and greenhouse gas emissions. This sector also bears responsibility for state oil dependence and local air quality and land use concerns. Cars and trucks are the most energy-intensive technology an average person owns—and California has almost as many cars as people. Under BAU conditions, transportation activity and energy consumption are expected to grow substantially faster than either population or the economy. The sheer number of vehicles and magnitude of driving activity also means that small changes have measurable impacts. Transportation policies, consumer preferences, or technologies that serve to increase fuel economy, decrease driving activity, or promote alternative fuel use offer large opportunities for reducing future energy consumption, decreasing pollution, and increasing energy diversity. The magnitude, impacts, and risks of transportation activities and oil consumption provide hearty justification for assertive transportation policy and planning on state and federal levels.

3. *The diversity of California's future electric power sector is highly uncertain*. Natural gas generation currently accounts for nearly 40% of generation serving California electricity demand. The future composition of California's power sector is uncertain, and current activities and expectations lead in competing directions. Long-term electricity contracts, largely for natural gas-based generation, negotiated during California's energy crisis promise to exert a major influence over the composition of electricity generation over the next 10 years. Post-energy crisis expectations for significant new natural gas capacity additions also reinforce the potential for dramatic increases in natural gas dependence. At the same time, the state's new RPS policy and increasing renewable energy activity in residential and municipal areas also assert the importance of renewable energy in the state's future. California currently has come to a cross-roads in its electricity sector, and the next decade will be a critical period in determining whether the state chooses a pathway of greater or decreasing energy diversity.

4. *Alternative pathways to BAU expectations are relevant and deserve attention*. California has a history of being a leader in energy innovation and policy, and is recognized for pursuing alternative pathways. The state now faces the challenge of continuing this legacy under the changing conditions of post-energy crisis. With a combination of public interest, industry cooperation, and policy leadership, California has enormous opportunities for pursuing cleaner energy pathways on both local and regional levels. As the pressures associated with continuing down a fossil fuel pathway continue to increase, alternative pathways will likely be viewed as even less "alternative" and more "necessary" in the future. Recognizing the value of alternatives earlier in its energy pathway offers even greater gains from earlier adoption. Scenarios offer a starting point for examining alternatives.

5. *Individual and community activities can and do make a difference*. The scenarios show that consumer preferences, household energy use, and community activities have a measurable impact on reducing energy consumption and increasing energy diversity. Use of solar water heaters, residential home and commercial solar electricity generation, energy efficiency, and fuel efficient and/or alternative fuel vehicle choices are some important ways that individuals and communities can and do make a difference to California's energy system. Community leadership may become one of the most critical driving forces for change in the future.

6. *Imports play an important role in state electricity generation and greenhouse gas emissions*. Energy imports exert a major influence on the availability, composition, and emissions associated with electricity generation serving demand in California. With the potential for natural gas capacity additions and the implementation of a new RPS policy, the role of electricity imports promises to be an area of extensive uncertainty.

Consideration of the future influence of imports in California on costs, reliability, and greenhouse gas emissions are important areas of focus for the future. An area that is critically important is for state-level greenhouse gas emissions reductions and mitigation activities to take into account not only in-state generation but also imports, as a measurable component of imports are derived from coal-based generation. Only by including all of its energy sources will accurate benefits and trade-offs of different climate change mitigation strategies be able to be assessed and implemented. California has the opportunity to take the lead in facilitating cooperative and planning efforts within the region.

7. *A combination of household, local, state, and national approaches offers the greatest gains in energy diversity*. Scenario analysis shows that the greatest decreases in energy consumption, increases in energy diversity, and reductions in greenhouse gas emissions are achieved from combining both state and national policy with individual and community activities. The level of individual responsibility and state planning are both important factors in the state's pathway. California has vast opportunities for encouraging and facilitating a combination of household, community, and centralized energy activities. National policy and incentives particularly in transportation also have a critical role in influencing California energy use. State, national, community, and individual actors share responsibility for shaping California's future energy pathway.

8. *A state renewable energy plan can provide a roadmap for the future*. For California to remain a leader in renewable energy and catalyze a supportive investment environment, the state needs to assert its commitment to renewable energy and transparently articulate the ways it will encourage these activities. The recent passage of a California RPS is an important step in this direction. The state now has the opportunity to develop a comprehensive, long-term vision for renewable energy policy and planning with participation of the public, industry, and other stakeholders. The RPS provides the ideal flagship energy policy for beginning this process of creating a state renewable energy framework and vision for future policy and planning. The form of incentives, purchasing contracts, standardization of interconnections, and utility cooperation are critically important areas for the future.

9. *Energy savings can play an important role in a California clean energy pathway*. Demand-side energy savings offer important opportunities for decreasing fossil fuel dependence, offsetting pollution, and increasing energy security. As a complement to supply side approaches, energy savings have an important role to play in California (Rufo and Coito, 2002). Equally important is the recognition that energy savings involve both energy efficiency and decreasing energy consumption, as both technologies and social choices have a role to play in California's energy pathway. Transportation offers the greatest opportunities for energy savings measures, for example increasing fuel economies of passenger and freight vehicles, development of alternative fuel vehicles and immediate low-tech options of walking, biking, public transit and increasing rider numbers per vehicle. Energy savings and energy efficiency are the most secure and least environmentally disruptive forms of energy "supply". Increasing the ability of individual and state planners to consider savings both from technologies and increasing social choices is important to realizing alternative pathways.

10. *Long-term visioning and cooperation starts now*. California has the opportunity to learn from its 50 years of experience in energy policy and planning. A critical lesson from the past is that policy vision and public leadership have inspired many of California's most highly regarded energy activities. In order for a new vision to emerge, it is necessary for the public, industry, government, and other critical stake holders to engage with the future. State leadership is needed to facilitate active discussion, participation, and consideration of alternatives for the future. Now is a critical time for the state to reorganize its energy planning activities, reassert its mandate for information gathering, and incorporate new ideas into its planning and forecasting purview.

17. Conclusions

Historically on the forefront of energy policy and technologies, California is, in many ways, both an example and indicator of the potential direction for future energy policy. Perhaps most significantly, California has conducted one of the most visible and highly scrutinized experiments in electricity deregulation in the world. Interpretation of California's deregulation experience and the success or failure of the state's subsequent energy pathway will have far-reaching implications for the future of energy policy both domestically and internationally.

Both the uncertainty and significance of California's current energy context validate the importance of the state's energy pathway. Expectations of how the forces of electricity deregulation were to shape the state's energy system have been turned on their head by the energy crisis. They have left in their place significant uncertainty about the future, where a unified and integrated vision for the future has yet to emerge. California currently faces a cross-roads in its energy pathway, and it is important to ask: *How will the state move forward into the next 30 years? What priorities will shape California's energy system? How might leadership emerge? What can be learned for making better decisions today?*

The scenarios presented here respond to these questions and demonstrate that plausible alternative energy pathways do exist. They do not predict what the future will be or even what it should be like. Rather they open the doorway to possibilities. The methods, tools, and examples presented here are a starting framework for beginning this discussion and an opportunity for creative engagement with the future.

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Appendix A. Background and assumptions for key scenario elements

A detailed treatment of background assumptions and justification for the scenario elements is summarized in Table 13.

Table 13

	Scenario attributes			Additional references
	Split Public	Golden State	Patriotic Energy	
Residential				
Solar PV[a]				
Household penetration, 2035	50%	30%	50%	
Total PV generation, 2035	13 TWh	7.7 TWh	13 TWh	
Implied total capacity	9 GWp	6 GWp	9 GWp	1 kW systems, 18.1 million households in 2035, based on 1.3% population growth/yr
Implied market sales growth	18%/yr	16%/yr	18%/yr	24%/yr Global PV Market Sales Growth since 1980 (Duke, 2002)
Assumptions	Continuation of California Energy Commission's Emerging Renewables (Buy-down) Program (see CEC, 2003a) Continuation of net metering legislation systems $\leqslant 1$ MW (California Legislative Counsel, 2002, Assembly Bill 58)			
Background data and supporting studies	CA Grid-Connected PV Capacity Installed: 44 MWp (CEC, 2003c) CA Buydown Program: 22 MWp small grid-connected PV installed; 11 MWp in processing, as of 9/15/03 (CEC, 2003b) CA Expected Buydown Growth: additional 100 MWp installed over next 5 years (Duke, 2002) Study of economics of solar PV industry learning curves estimates historical learning rate of 20% for each doubling of production based on literature review (see Duke and Kammen, 1999) Study of solar grid-connected PV market potential under PV buydown scenario. By 2030 module retail prices drop \$4/Wp to \$0.60/Wp, global PV sales $\geqslant 100$ GWp/yr, corresponding to 9 doublings of cumulative production (implied learning rate of 21%) (see Duke, 2002)			
Transportation				
Penetration, 2035				
Hybrid and electric vehicles	50%	30%	60%, 2020	

(continued on next page)

Table 13 (*continued*)

	Scenario attributes			Additional references
	Split Public	Golden State	Patriotic Energy	
			25%, 2035	
Fuel cell vehicles	0%	0%	75%	
Assumptions	Manufacturing costs reductions, production scale economies, technological experience curves (see Lipman et al., 2000)			
Background data and supporting studies	Scenario study of fleet-wide vehicle manufacturing costs and retail prices, total lifecycle costs of vehicle ownership and operation, vehicle running and upstream emissions, and emissions control and damage costs from 2003 to 2030, based on CA South Coast Air Basin (see Lipman et al., 2000) *Scenarios* (Lipman et al., 2000)*:* High gasoline hybrid vehicle (HEV): >80% penetration by 2030 Medium fuel cell electric (FCEV): HEV >20%, FCEV >50% by 2030 High fuel cell electric (FCEV): FCEV >90%, Battery EV ~10% by 2030 *Result* (Lipman et al., 2000)*:* High HEV is win–win scenario with lifecycle ownership and operation cost savings and modest emissions reductions versus conventional vehicles (fuel savings exceed difference in manufacturing cost of \$2300–\$4000) High-volume production costs of FCEVs remain above conventional vehicles; lifecycle costs comparable at ~\$1.90–1.95/gal of gasoline. At \$2.00/gal, High FCEV scenario yields slightly lower lifecycle based vehicle plus emissions plus infrastructure costs (−0.5%) than conventional vehicle scenario. At \$1.60/gal, incremental lifecycle costs increase 2%.			
Commercial[a]				
Cumulative additions, 2035				
Wind	600 MW	360 MW	600 MW	
Solar	1240 MW	740 MW	1240 MW	
Total generation, 2035				
Wind	1.6 TWh	1.0 TWh	1.6 TWh	
Solar	2.8 TWh	1.8 TWh	2.8 TWh	
Assumptions	Expansion of Municipal Renewable Energy Initiatives following model of San Francisco Propositions B and H, expected to finance 60 MW of solar and 30 MW wind (California Solar Center, 2002a, b) California municipal initiatives have large potential; San Francisco represents approximately 2% of the state population; CA has 59 cities with >100,000 people and 15 cities >200,000 (City Population California, 2003)			
Implied expansion factor:	20	12	20	Relative to San Francisco initiatives
Electricity[a]				
Total generation, 2035	520 TWh	522 TWh	509 TWh	
Natural gas (TWh) (% total)	276 (53%)	260 (50%)	239 (47%)	
Renewables (*non-hydro*)	55 (11%)	107 (20%)	116 (23%)	
Wind (TWh) (%)	18 (3%)	58 (11%)	62 (12%)	
Geothermal (TWh) (%)	26 (5%)	38 (7%)	44 (9%)	
Biomass[b] (TWh) (%)	10 (2%)	9 (2%)	10 (2%)	
Assumptions	Natural gas additions for BAU and Split Public derived from CEC's "most likely" and "baseline" scenario categories (CEC, 2002b, Table I-2, II-2-1) Renewables generation shares based on California Energy Commission renewable energy resource assessment scenario (60% wind, 25% geothermal, 15% biomass) (see CEC, 2003d, 26) Continuation of National Wind Production Tax Credit, 1.5 cents/kWh Golden State: CA Renewable Portfolio Standard (RPS) law as of 9/02, 20% by 2017 (California Legislative Counsel, 2002, Senate Bill 1078) Patriotic Energy scenario National RPS of 20% by 2020			
Background data and supporting studies	California Renewable Energy Resource Assessment estimated range of renewable generation potentials, based on various studies (see CEC, 2003d): Wind: 27–86 TWh/yr Geothermal: 28–104 TWh/yr Biomass: 10–28 TWh/yr Solar: 60–128 TWh/yr Study quantifying 80 m wind power from 10 m measurements finds US wind power may be substantially greater than previously estimated. Winds over possibly one fifth of the US are strong enough to provide electric power at a direct cost equal to that of a new natural gas or coal power plant. CA ranks 10th in numbers of ⩾ class 3 sites (Archer and Jacobson, 2003) Estimate CA on-land wind potential (AWEA, 2003): 59 TWh/yr, 20 GW			

Table 13 (*continued*)

	Scenario attributes			Additional references
	Split Public	Golden State	Patriotic Energy	
	CA wind generation potential study (see Land and Water Fund of the Rockies, Northwest Sustainable Energy for Economic Development and GreenInfo Network, 2002): Based on 1992 CA data (considered conservative estimates) CA Wind-derived on-land potential (⩾Class 4 sites): 45 TWh/yr CA Wind development potential land area (⩾Class 4): 729,000 acres Key sites in CA include: Solano County, Altamont Pass, Pacheo Pass, San Gorgonio Pass, Tehachapi, and others			

[a] Small-scale distributed generation of electricity within the residential and commercial sectors from solar PV and wind are modeled within residential and commercial demand sectors themselves rather than within the electricity sector. Modeling in this way makes it possible to track the level of electricity demand that is offset, or more accurately, relocated from within the state electricity system to self-generation within the residential and commercial sectors. Residences and businesses are assumed to remain net consumers rather than producers of electricity.

[b] Biomass category also includes a small amount of digestor gas, landfill gas, and municipal solid waste.

Appendix B. Sources of the California Energy Dataset

The sources used to develop the California energy database are referenced in Table 14

Table 14

Category	Source
Residential	EIA (1995, 1999b, 2000b), PG&E (1994), RLW Analytics (2000), and Wenzel et al. (1997)
Transportation	BTS (2001), CalTrans (2000, 2001), CARB (2001), CEC (2000b, 2001a, 2002c, d), EIA (1999a, 2000a, 2001c, e), FHA (2001), Levin et al. (2001), Lipman et al. (2000), Mark and Morey (2000) and PG&E (2002)
Commercial	ADM Associates (1997), BEA (2001), CEC (2001c) and XENERGY (2002)
Industrial	BEA (2001), CEC (2001e) and XENERGY (2001)
Electricity generation	Bachrach (2002), Brown and Koomey (2003), CEC (2000c, 2001b, d, g, h, 2002a, b, g, h), EIA (2000c, d, 2001a, b) and EPA (2001)
Emissions	CEC (2001f, 2002f), EIA (2001f), EPA (2001), IPCC (1997) and Nakicenovic and Swart (2000)
Multiple sectors/fuels	CEC (1998, 1999, 2000a, 2001b, f, 2002b), EIA (2001d, h) and Schipper and McMahon (1995)
Population and economy	BEA (2001), EIA (2001g); LAEDC (2001) and US Census (1999a, b, c, 2001)

Appendix C. Scenarios resources

Scenarios resources (see Table 15).

Table 15

Sector category	Source
Scenario planning and forecasting methods	Ascher (1978), de Geus (1998), Kleiner (1990), Ringland (2002a, b), Schwartz (1991), van der Heijden (1996) and Wack (1985a, b)
Energy and environment scenarios	Brown et al. (2001), Gallopin and Raskin (1998), Ghanadan (2002), Gumerman et al. (2001), Harris (2002), Interlaboratory Working Group (2000), Lovins (1979), Nakicenovic and Swart (2000), Raskin et al. (1998, 2002), Ross (2001), Schipper and Meyers (1993), Shell (1999, 2001, 2002) and World Business Council for Sustainable Development (2000)
Future energy trends	Clean Edge (2002), Clemmer et al. (2001), Dunn (2000), Makower and Pernick (2002), NEP (2002), Reddy et al. (1997) and World Energy Council (2000)

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