POWERING CALIFORNIA

The Monterey Shale & California's Economic Future

A Research Study Conducted By The

USC Price School of Public Policy
USC Global Energy Network
University of Southern California

In association with

the communications institute

This research is presented in the public interest by the USC Global Energy Network, the USC Price School of Public Policy and The Communications Institute. The study was conducted by a team of researchers from the Price School to examine the economic impacts of Monterey shale-oil development on the California economy. Results of ongoing research on related technology requirements and environmental issues by the Viterbi School of Engineering are not part of this report, but will be released upon their completion.

The goal here is to provide the public and the policy makers at all levels with better information and knowledge to make better decisions for the benefit of society. This study and the related conclusions are based on careful analysis of available data from United States Department of Energy, industry, and other sources. However, the available data are limited, as noted throughout this report, and thus the current report represents only a preliminary overview of the economic impact that development of the Monterey Shale could have on California.

Many of the technical, practical and environmental challenges are not addressed in this report. More conclusive estimates will require more reliable production data from both the government and producers and a more comprehensive study of the environmental impact of shale-oil production. This study does not offer any conclusions or judgments as to the operational, environmental, and regulatory practices involved with the use of advanced extraction technologies in the development of shale oil.

This study is also part of a long series of studies and educational programs conducted since 2003 by The Communications Institute in association with other institutions. The first portion of the study was contributed by the Institute. This is the Institute's third report on state energy issues, which have also been co-sponsored by other institutions, including the Arizona State University School of Business.

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Preface

Many of the challenges, problems, and issues facing our society are not new. As Herman Melville in *Moby Dick* reminded us, "Verily there is nothing new under the sun." In looking at some of the major challenges facing California and our nation, it is as true as it was in Melville's time that the challenges of the day, while different in their particulars, are not fundamentally new. We have been there before.

An Historical Perspective

This observation is especially true with regard to issues relating to resource development, as historically the development of natural resources has been a key to California's economic growth and progress. For example, the Gold Rush of the late 1840s was the impetus for California's early growth. Historians note that the Gold Rush was "arguably one of the most significant events to shape American history during the first half of the 19th century." In a remarkably short period of time, more than 300,000 people came to California from around the world to search for gold. San Francisco was a sleepy little town of 200 in 1848, but in just four years it swelled to 36,000. Ultimately, the California Gold Rush resulted in more than $19 billion in current dollars of the precious metal's being extracted by just 1852.

The State's experience with water resources was similar. As the California State Department of Water Resources notes, following the Gold Rush, many of the "49ers" migrated into the rich rural valleys of central California to create the State's agricultural industry. Newly growing cities like those in the Bay Area needed water and power, and mammoth projects like the Hetch Hetchy reservoir and electrical generating plant near Yosemite were eventually built. Adequate access to water therefore served as an important factor in California's maturing economic growth.

While the Gold Rush took place in Northern California, another kind of "gold" was growing in importance in Southern California: "black gold." General Andreas Pico, a former military commander in the Mexican Army and lifelong Californian, took tar from hand-dug pits in Los Angeles and distilled it to produce lamp oil. His efforts were the beginning of another kind of "gold rush" for California—a rush for oil that would dramatically transform the State and not only serve as a vital energy resource for California but also as a key driver of the State's economy, inaugurating a role that oil has played in the State for more than 160 years. Consider these early landmarks in the development of oil in California:

- 1866 First steam-powered rig in California drills an oil well at Ojai.
- 1875 State's first commercially viable oil field is discovered at Pico Canyon in Los Angeles County.
- 1899 Discovery of Kern River oil field propels Kern Co. to top oil-producing region in State.
- 1899 A new era of petroleum-fueled transportation begins with the conversion of locomotive engines from coal- to oil-burning.
- 1904 The production of 17.2 million barrels of oil takes place at Kern River, exceeding the total annual production from Texas.
- 1916 The economic value of the production of oil and gas in the State exceeds that of gold.

The oil industry grew rapidly and enriched the citizens of the State, its educational institutions, governments at all levels, and other public and commercial entities. Like the earlier Gold Rush, California's "oil rush" made a positive contribution to the State's economic well-being, but there were costs as well. With all of the benefit of the original California Gold Rush, for example, the mining and population influx certainly had an adverse impact on the once-pristine Sierra Nevada Mountains, and the remnants of placer mining from 1850s still can be seen in the massive piles of rocks throughout the Sierra foothills. Concerns with California's oil boom also remain to this day in the ongoing debates over the environmental consequences of both onshore and offshore oil-drilling.

Over the past several decades, the increased development and use of fossil-fuel energy within California has posed its own set of challenges. Among these were emerging risks to the State's air, water, and other natural resources. And yet, while the natural beauty of California had long been the pride of its citizens, it was not until the 1960s that the State's leaders, across the political spectrum, took action to attempt to balance the enormous contribution of industrial growth with the preservation of the State's natural resources and environment.

Enter the Monterey Shale

As it happens, the need for striking a similar balance is re-emerging today—centered, once again, on the role of the State's natural resources in its economic growth and development. As has been well-documented, California's in-state production of energy has been declining in recent years, and the State has been forced to import an increasing proportion of the energy resources. More recently, the State has faced severe economic challenges, with high unemployment, plummeting home values, and stagnant or declining tax revenues at all levels of government—problems aggravated by a long and, in some respects, enduring national economic recession. Economic conditions throughout the State have thus fallen short of what they had reached in California's golden years. Many observers and residents alike have been left to wonder whether the State's best days are behind it.

Fortunately, such troubling epitaphs may be premature. In spite of these worrisome conditions, a new, potentially economy-spurring natural resource has gained prominence. That resource is the Monterey Shale Formation, a 1,750-square-mile swath of mostly subterranean shale rock that runs lengthwise through the center of the State. The Monterey Shale Formation represents some two-thirds of the United States' shale oil reserves, a total resource base of more than 15 billion barrels of oil. Were that oil to be aggressively developed, not only could California's—and, indeed, all of America's—energy imports be significantly reduced, but statewide economic benefits ranging from enhanced economic growth to dramatically increased government revenues could be reaped.

But herein lies the challenge. For the most part, oil locked within the Monterey Shale can be efficiently developed only with advanced oil-extraction technologies, including hydraulic fracturing and horizontal drilling. While these technologies are new to most people, they have been shown in numerous fields of operation to be potentially significant contributors to the production of energy resources. But these technologies— in particular hydraulic fracturing—may pose certain environmental risks. And so a key public policy question arises: do the potential benefits of developing the Monterey Shale outweigh the possible costs and risks? We seek to address this question in two parts. In the current study, we focus on the potential economic impacts within the State of California of aggressively developing the Monterey Shale. In a subsequent report, we will assess the environmental implications of such a course of action.

Our research team is both committed to exploring these latter topics and is, in fact, well-prepared to do so. Among the environmental concerns that have been raised in the past about particular advanced extraction technologies are potential water contamination and the creation of artificial earthquakes. USC's Viterbi School of Engineering is already assessing these vital matters through initiatives such as USC's Induced Seismicity Consortium (ISC), which is focused on earthquakes. Among the technical challenges involved are optimizing the multi-stage fracturing process using micro-seismic monitoring. This topic is being addressed through the USC Reservoir Monitoring Consortium (RMC). More broadly, increased reliance on oil as part of the State's (and the nation's) energy portfolio has implications for the continued production of "criteria" air pollutants and greenhouse gases. These issues are also being examined in the Price School of Public Policy and others at USC.

While the economic impact of developing the Monterey Shale is important, we also recognize that it is critical as well to properly address the environmental and technological challenges like those just enumerated. It is clear from the history of nearly two centuries of resource development in California and the United States as a whole that economic and industrial growth can prompt both positive and negative effects on people, places, and policy. The task of policymakers is to sort through the claims and counterclaims of the various proponents on all sides of the issues in order to ensure that the overall public interest (and people's health and safety in particular) is well-served. In the case of California, which has faced economic difficulties in recent years, the need for a clear understanding of the potential economic contribution that a resource like the Monterey Shale can make is especially important. As such, all relevant environmental and technological issues deserve serious research, analysis, and reflection, and we will address them specifically and in detail in a series of follow-on reports.

In the current report, while acknowledging the concerns, we seek only to answer the first of the two questions referenced above: what are the potential economic impacts for California of developing the Monterey Shale? In addressing this question, we make no policy or regulatory recommendations, leaving that task to policymakers and government leaders. Rather, we seek to provide only a solid, if preliminary, intellectual foundation for making an assessment—in the hope that a richer base of information will lead to improved policy decisions for the people and businesses of California, and for the State as a whole.

Sincerely,

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We wish to thank our institutional sponsors for this project, without whose support this work could not have been possible. These sponsors include:

Price School of Public Policy. The mission of the USC Sol Price School of Public Policy is to improve the quality of life for people and their communities, both in the United States and abroad. It is one of the top ten public policy schools in the nation and has a distinguished international reputation. USC is one of the nation's major research universities and the oldest in the West, and the USC Price School is a renowned contributor to the university's reputation. Much of the school's research is conducted through its centers, institutes and research groups. Price achieves this mission through education and research that promote innovative solutions to the most critical issues facing society including five master's level programs—in Public Policy, Public Administration, Urban Planning, Real Estate Development and Health Policy and Management—join theory with practice and emphasize experiential and professional learning.

The Communications Institute. The Communications Institute (TCI), founded in 2003, has for more than a decade conducted research and educational programs focused on objective, non-partisan analysis of critical public policy issues as a resource for citizens, government, business and community leaders, and journalists. The Institute research and programs has involved many leading academic and research institutions as partners or cosponsors including the RAND Corporation, USC, Caltech, the Wharton Business School of the University of Pennsylvania, the University of California, Pennsylvania State University, University of Arizona, Arizona State University, and Stanford University.

Research Team

We acknowledge the contributions of members of the research team. **Peter Gordon, Ph.D.**, Professor in the University of Southern California's Sol Price School of Public Policy, has extensive experience in analysis of regional economic impacts of private sector decisions and public policy. **JiYoung Park**, **Ph.D**., Assistant Professor, School of Architecture and Planning, University at Buffalo, who received his Ph.D. from USC, has expertise in economic modeling and **Arman Khodabakhshnejad,** a Research Assistant in Viterbi School of Engineering, USC, possess significant expertise in oil-production engineering, mining, and modeling, working towards his PhD degree under Prof. Fred Aminzadeh.

It should be emphasized that research on many of the engineering aspects of the study are still ongoing and the preliminary results reported here may be very optimistic. The full analysis of the technology requirements and environmental issues by the Viterbi School of Engineering are not part of this report and will be released upon their completion.

Also assisting in the development of this study were: **Kevin Hopkins**, Director of Research for The Communications Institute; **Dan Wei, PhD.,** Research Assistant Professor, Price School of Public Policy, USC; and **Adam Rose**, Ph.D., Research Professor at USC's Sol Price School of Public Policy. Dr. Rose, who has conducted extensive research on the economics of energy and on climate change policy, coordinated the efforts of various members of the research team.

We also want to thank Dr. Hillard Huntington, Executive Director of Stanford University's Energy Modeling Forum, and Dr. Henry Lee, Director of the Environment and Natural Resources Program and Senior Lecturer in Public Policy at Kennedy School of Government, Harvard University, for taking the time to review this study. We also appreciate the analysis of Dr. Craig Smith, Research Professor, Naval Post-Graduate School, and former Deputy Associate Director of the Energy Directorate, Lawrence Livermore National Laboratory, United States Department of Energy.

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We also want to thank Jack Knott, Dean of the Price School, for his encouragement and support of this study through the contributions of members of the School's Faculty. Dr. Knott also serves as Chairman of the Board of Trustees of The Communications Institute, which has conducted other major studies on energy, immigration, and state fiscal management.

We recognize the need for objective analysis of critical issues at a time when they are often presented from extreme points of view. To this end, we plan in ensuing months to conduct additional research that will examine some of the vital environmental and planning issues that surround the impact of the expansion of enhanced oil-extraction technologies in California.

Executive Summary

The Monterey Shale Formation in California, like other shale oil and gas reserves around the nation, has been widely cited as a potential "gold mine" of oil resources in California. Recent headlines attest to its increasing role in the California energy debate:

- "*Monterey's black gold could jumpstart California's Economy*" (Los Angeles Daily News)
- "*Could Monterey Shale Save California?*" (Investors.com)
- "*The battle is heating up over California's vast Monterey shale field*" (Examiner.com)

There is good reason for this interest: the Monterey Shale contains an estimated 15-plus billion barrels of oil, representing more than two-thirds of all known U.S. shale reserves. But the story is not quite so simple. Oil cannot be extracted from deep shale formations like Monterey through the use of conventional oil wells, like those that dot many California landscapes. Rather, advanced oil-extraction technologies, like hydraulic fracturing and horizontal drilling, are required.

Hydraulic fracturing, a well-established, advanced means of extracting oil and natural gas from sub-surface shale formations, has emerged in particular during the past several years as a technique with high potential for increasing the volume of oil and natural gas producible within the United States. The technique has been employed over the past decade in the Northeast and Upper Midwest, primarily in the production of natural gas, and was cited last year by the International Energy Agency as a key factor in the possibility that the United States soon could achieve the long-sought goal of net energy self-sufficiency.

However, advanced extraction technologies like hydraulic fracturing are not without their critics. The technique has been blamed for such adverse environmental consequences as ground water contamination, excessive wastewater production, increased seismic activity, and transportation and land-use challenges. Such problems, were they to materialize in any major way in California, could overwhelm the proposed benefits of developing the Monterey Shale, with the unfortunate result that the more widely spread usage of the associated extraction technologies could wind up doing more harm than good. While some analysts and proponents of hydraulic fracturing assert that these concerns either are overstated or could be adequately addressed through effective regulation or remediation, the balance of benefits and costs has not yet been definitively established.

The Purpose of This Report

The purpose of this report is to conduct an objective and economically sound assessment of the net benefits and costs of the increased use of hydraulic fracturing in California, especially with regard to the production of oil from the State's Monterey Shale Formation. In carrying out this assessment, this report addresses two primary questions relating to whether California should consider expanding the use of hydraulic fracturing in the production of oil from the Monterey Shale. Specifically:

- To what extent could advanced extraction technologies like hydraulic fracturing increase the production of oil from the Monterey Shale Formation?
- Given the projected increases in the production of oil, what would be the likely near- and mid-term effects on incomes, employment, and government tax revenues collected in the State?

This report is intended to set forth facts and projections with regard only to the potential economic impacts of the prudent development of oil from the Monterey Shale—and to do so as clearly and objectively as possible—in order to serve as a foundation for informed decision-making. It is the responsibility of others, both within and outside government, to weigh any potential environmental effects and their possible prevention or remediation, and to actually make the policy and regulatory decisions as they bear on such questions. The research presented in this report therefore should be considered a first exploration into the topic, and not a definitive assessment. As such, a detailed exploration of the potential environmental ramifications of the envisioned resource development needs to be undertaken.

Energy and The Economy In California

Once an economic powerhouse, California has faced serious economic challenges in recent years. Falling housing prices, persistent unemployment, and stagnant or declining revenues at all levels of government have imposed tough choices on State and local political leaders even as these problems have undermined living standards and the quality of life for many Californians. Although some efforts of Governor Brown and the State Legislature to cope with these challenges may be starting to bear fruit—and although California remains a national leader in innovation and creativity—most observers believe that the State faces a long road to full economic recovery.

This report provides an indication that there is one potential bright spot in California's economic future: the increased production of energy. California has long served as the incubator for emerging energy sources and technologies, as the State has taken advantage of both technology and its natural resources to become a leader in the generation of renewable energy. Now, these same technological and resource advantages can allow the State to return to leadership in the production of oil.

One might conclude that increased oil production was unlikely given recent historical patterns: according to the California Energy Commission, California's crude oil production fell by 47% between 1985 and 2010, with offshore production dropping by more than half. And yet the recent experience in other states is instructive. North Dakota, South Dakota, Wyoming, Pennsylvania, Ohio, and Texas are witnessing powerful economic revivals stimulated in large part by the boom in energy production within their borders. In North Dakota, for example, as oil production soared from about 200,000 barrels per day in 2008 to more than 750,000 barrels per day in 2012 (and as natural gas production throughout the State grew similarly), the State's gross domestic product grew by an average of 6.7% for the years 2008 to 2011, the nation's fastest growth rate, while unemployment fell to 3.2%, the nation's lowest.

A key source of the North Dakota energy boom has been the extraction of energy resources from deep-shale reserves (specifically, the Bakken Shale Formation)—as Pennsylvania has benefited from development of the Marcellus Shale—primarily through an advanced extraction technology known as hydraulic fracturing. Hydraulic fracturing and other advanced techniques, in fact, underlie forecasts of an oil and gas production boom throughout the United States and worldwide in the decades ahead. For instance, in its World Energy Outlook 2012, released last November, the International Energy Agency (IEA) projected that, by 2035, the United States would become 97% energy self-sufficient in net terms—a sharp reversal from recent increases in U.S. import-dependency—in large part due to the surge in advanced-technology gas production (and, to a lesser extent, in advanced-technology oil production). Indeed, on a worldwide basis, the IEA forecast that fully half of the global increase in natural gas production through 2035 would be due to advanced oil- and gas-extraction technologies like hydraulic fracturing.

Why are these trends relevant for California? Simply put, California boasts perhaps the largest deep-shale reserves in the world—reserves that, unlike elsewhere, hold the promise not so much for natural gas production, but for an unprecedented volume of advanced *crude oil* production. Specifically, according to the U.S. Energy Information Administration, whereas California's well-known *offshore* reserves contain more than 10 billion barrels of oil and nearly 12 trillion cubic feet of natural gas, the State's far less well-known onshore Monterey Shale formation may contain even more oil—more than 15 billion barrels—but which does not involve the expense and environmental risks of deep-ocean drilling.

And so a tantalizing series of questions arise. Can California successfully exploit the economic and energy benefits of its indigenous deep-shale reserves in a parallel manner to what other states have accomplished (even while continuing innovation in the renewable-energy sector)? How significant are the potential benefits for California—not only in terms of energy production, but also in terms of economic growth, job creation, and government tax revenues? And can these in-state energy reserves be developed in ways that are not only economically practical, but environmentally safe as well (complementing energy and conservation policies enacted by the state over the years)?

Economic Impact of Oil Production from the Monterey Shale

In order to address these questions, this report estimates the macroeconomic impacts of expanded advanced extraction technologies, particularly hydraulic fracturing, in the production of oil from the Monterey Shale Formation. Describing economic impacts some years into the future is challenging and requires great care. We therefore do so in this report as realistically and objectively as possible. Specifically, we project California GDP per capita for selected years, to 2030, under various California oil production scenarios. From GDP per capita, we estimate impacts on jobs, personal income and tax collections. Our approach is to estimate and apply economic growth models that use available data and credible econometric methods.

Economic booms from new oil and gas drilling have recently been experienced in various states. These are a matter of record and we seek to learn from them. What if California experiences similar drilling opportunities? What would be the economic effects? Generally speaking, there are two parts to our approach. First, we consider alternate California multi-year oil drilling scenarios to 2030 (base case vs. high and low enhanced drilling scenarios); second, we seek to simulate how the California economy might respond by studying the experience of the recent oil boom states. The economic impacts in these states have been widely reported and are significant.

The main results of our work are shown in Table ES1 below, which reports the most conservative path, relying upon what we call the "North Dakota" scenario and involving the most moderate expansion of the oil-boom states for the years for which we have all of the required data. (The most recent and most spectacular years of North Dakota's performance are therefore not included.) These simulations evaluate alternative California oil-drilling possibilities elaborated in Appendix K.

Shale technology, as opposed to many other technologies on the horizon, is currently competitive. The two enhanced drilling cases involve a low "adapted EIA advanced-technology oil drilling scenario" and a high "projected advanced-technology oil well drilling scenario." However, because modeling extraordinary impacts is always a challenge, precise forecasts are not really feasible; instead, we are interested mostly in *patterns* of development. It therefore makes the most sense to emphasize a set of median (half-way) scenario results. That scenario suggests 512,000 to 2,815,800 new jobs, depending on the year. This represents an increase in the number of jobs in the State of from 2.1% to 10.0%.

We also should be mindful that the North Dakota experience shows that an oil boom can prompt significant in-migration of labor. In just the one year ending July 1, 2012, for instance, North Dakota's population grew by 2.17 percent while the overall U.S. population grew by only 0.75 percent. Therefore, should these scenarios evolve as described, California not only would likely gain a significant number of jobs, but would experience nontrivial population growth as well.

There are other important economic effects as well. For instance, in the median case, depending upon the year:

- State per-capita gross domestic product (GDP) grows by $1,600 to $11,000, or by 2.6% to 14.3%.
- Personal income grows by $40.6 billion to $222.3 billion, or by 2.1% to 10.0%.
- State and local government revenues (tax collections) grow by $4.5 billion to $24.6 billion, or by 2.1% to 10.0%.

Table ES1. Overview of Incremental California Economic Impacts

	Year	Baseline	Increment
Per Capita GDP ($) The amount of economic activity within the state, divided by the number of people in the state	2015	62,000	1,600
	2020	72,000	10,300
	2025	82,000	11,000
	2030	93,000	8,300
Employment (jobs) The total number of people employed in the state	2015	24,329,100	512,000
	2020	28,253,200	2,815,800
	2025	32,177,200	2,652,800
	2030	36,493,700	1,770,900
Personal Income ($ millions) The total of all income earned by all people within the state	2015	1,928,600	40,600
	2020	2,239,700	223,200
	2025	2,550,700	210,300
	2030	2,892,900	140,400
Tax Collections ($ millions) Tax revenue (tax collections) by state, local, & county government	2015	212,900	4,500
	2020	247,300	24,600
	2025	281,600	23,200
	2030	319,400	15,500

Notes: 1. Median drilling case indicates the economic increment from baseline values of that year.
2. Values are rounded and elaborated in Tables 12.1.a-12.2.b.
3. Baseline values are values that would exist in the absence of accelerated shale-oil development.
4. Incremented values are additions to baseline values that result from accelerated shale-oil development.

Conclusion

As the experience in North Dakota, South Dakota, Wyoming, and elsewhere demonstrates, jurisdictions that have made a commitment to developing their in-state shale-oil reserves have experienced significant economic booms, resulting in large and positive impacts on incomes, employment, and government revenues. The current report suggests that, through the prudent and carefully regulated development of the Monterey Shale, the State of California likewise could achieve proportionately large increases in the production of crude oil, leading to similarly large and positive impacts on incomes, employment, and government revenues within the State.

Chapter 1. Introduction

By Kevin Hopkins

Since the days of the Gold Rush, California for many years has been the economic gem of the United States. As a top destination for America's most creative and industrious individuals—men and women plying their talents in Hollywood and Silicon Valley, in the rich agricultural valleys of the State's heartland and in some of the nation's premier educational institutions—California has played a leading role in driving U.S. economic growth, productivity, and innovation. And yet the State accomplished all of this while forging a commitment to conservation and environmental protection that was unrivaled throughout America. The California experience was powerful proof that economic opportunity and environmental preservation could successfully be pursued hand-in-hand.

Unfortunately, California's economy has fallen on difficult times—conditions that jeopardize both the State's economic and environmental gains. Falling housing prices, persistent unemployment, and stagnant or declining revenues at all levels of government have imposed tough choices on State and local political leaders even as these problems have undermined living standards and the quality of life for many Californians. Although some of the efforts of Governor Brown and the State Legislature to cope with these challenges may be starting to bear fruit—and although California remains a national leader in innovation—most observers believe that the State faces a long road to full economic recovery.

Even California's once-dominant energy industry has suffered. According to the California Energy Commission, California's crude oil production fell by 47% between 1985 and 2010, with offshore production falling by more than half. As a result, by 2010, foreign oil imports into the State were more than 70% greater than the levels of 2000, and more than five times greater than they were in 1985. And the future does not look much brighter: the Los Angeles Economic Development Corporation forecast that, for the period 2005 to 2019, California's in-state crude oil production would decline by 39%, from 696,000 barrels per day in 2005 to 423,000 barrels per day in 2009.

Why single out the State's declining in-state energy production in assessing the State's economy? Quite simply—in California and elsewhere—energy is one of the essential engines of economic growth. To be sure, one of California's political success stories in recent decades has been its highly effective energy-conservation and renewable-energy initiatives. According to the most recent data from the U.S. Energy Information Administration, California ranks 47th out of 50 states in per-capita energy usage, with its per-capita energy use almost 30% lower than the national average. Looked at another way, despite the State's being home to 12.4% of the total U.S. population, California accounts for only 8.6% of total U.S. energy consumption and only 9.6% of total U.S. petroleum consumption. And even with the State's reputation as an automobile-dependent culture, California also uses well less than the average of U.S. motor-vehicle gasoline—only 10.9% of the U.S. total.

And yet, these impressive conservation improvements notwithstanding, California will require more conventional energy in the future—much more—if the State is to return to its historical patterns of strong economic growth and robust job creation. As the California Council on Science & Technology projected in a May 2011 report, "by 2050, California's population is expected to grow from the 2005 level of 27 million to 55 million. Even with moderate economic growth and business-as-usual (BAU) efficiency gains, [California] will need roughly twice as much energy in 2050 as we use today." The Council's forecast implies an average annual increase in statewide energy usage of approximately 1.6%, which is expected to support annual economic growth rates of up to twice as great during this period.

But there is another, even more interesting, prospect than this: the possibility that greater-than-expected in-state energy production not only could *support* a return to stronger economic growth within the State, but actually *accelerate* the State's economic turnaround, perhaps profoundly so. States like North Dakota, South Dakota, Wyoming, Pennsylvania, Ohio, and Texas are already witnessing powerful economic revivals prompted in large part by the boom in energy production within the states. In North Dakota, for example, as oil production soared from about 200,000 barrels per day in 2008 to more than 750,000 barrels per day in 2012 (and as natural gas production throughout the State grew similarly), the State's gross domestic product grew by an average of 6.7% for the years 2008 – 2011, the nation's fastest growth rate, while unemployment plummeted to 3.2%, the nation's lowest.

A key source of the North Dakota energy boom has been the extraction of energy resources from deep-shale reserves—specifically, the Bakken Shale Formation—primarily through a process known as hydraulic fracturing. Hydraulic fracturing and other advanced oil and gas extraction technologies, in fact, underlie forecasts of a veritable oil and gas production boom throughout the United States and worldwide in the decades ahead. For instance, in its World Energy Outlook 2012, released last November, the International Energy Agency (IEA) projected that, by 2035, the United States would become 97% energy self-sufficient in net terms—a sharp reversal from recent increases in U.S. import-dependency—in large part due to the surge in advanced natural gas production (and, to a lesser extent, in advanced-technology oil production). Indeed, on a worldwide basis, the IEA forecast that fully half of the global increase in natural gas production through 2035 would be due to advanced oil-extraction technologies like hydraulic fracturing.

Why are these trends relevant for California? The answer is straightforward: California boasts perhaps the largest deep-shale reserves in the world—representing two-thirds of total U.S. shale reserves—reserves that, unlike elsewhere, hold the promise not so much for natural gas production, but for a perhaps unprecedented volume of advanced *crude oil production*. Specifically, according to the U.S. Energy Information Administration, whereas California's well-known *offshore* reserves contain more than 10 billion barrels of oil and nearly 12 trillion cubic feet of natural gas, the State's far less well-known onshore Monterey Shale formation may contain even more oil—as much as 15 billion barrels—that does not involve the expense and environmental risks of deep-ocean drilling. By contrast, in 2010, California's annual crude oil production was approximately 224 million barrels of oil.

And so a tantalizing series of questions arises. Can California successfully exploit the economic and energy benefits of its indigenous deep-shale reserves in a parallel manner to what other states have accomplished? How significant are the potential benefits for California—not only in terms of energy production, but also in terms of economic growth, job creation, and government tax revenues? And can these in-state energy reserves be developed in ways that are not only economically practical, but environmentally safe as well? What are the key specific technical challenges and the environmental issues for Monterrey shale development compared to other shale formations such as Bakken shale?

It is to the resolution of these important—even vital—questions that this report is dedicated.

Chapter 2. California's Energy Future: An Overview

By Kevin Hopkins

The announcement of the impending end of America's enduring dependence on imported energy—an event with as much potential significance for California as for the nation as a whole—came quite unexpectedly. In its "*World Energy Outlook 2012*," released on November 12, 2012, the International Energy Agency (IEA) projected that, by 2035, the United States would become "97% energy self-sufficient in net terms, as exports of coal, gas, and bioenergy… help offset… the declining net imports of oil…" For oil alone, the IEA forecast that U.S. net imports would fall by nearly two-thirds, from 9.5 million barrels per day (mb/d) in 2011 to 3.4 mb/d in 2035. As a result, "the United States is projected to reduce its reliance on imported oil from more than 50% of consumption today to less than 30% in 2035, while becoming a net exporter of gas" (p. 76).

This declining reliance on imported oil, the IEA notes, would make the United States unique among the world's largest energy consumers. "By reversing the trend towards greater dependence on imported energy," writes the IEA, "the United States stands out from most other major energy-consuming regions and countries." For example, "China, India, ASEAN, and the European Union all see a steady move toward greater reliance on imports" (p. 76).

U.S. Energy Demand & Supply

The IEA's rather surprising assessment of the U.S. energy future is based on several factors that themselves run counter to the conventional views of American energy dynamics. One such factor is the powerful role played by energy conservation and energy efficiency (conservation that more than pays for itself through fuel cost savings). Due in large part to the increasing success of such efforts in the U.S.— including auto-mileage standards, building codes, and other government regulations, as well as individually motivated responses to market conditions — the IEA is able to project a net reduction in U.S. energy demand over the period 2010 through 2035 (see Table 1).

Table 1. U.S. Energy Demand, 1990 – 2035

	Energy Demand (Mtoe)							**Shares (%)**		**CAAGR (%)**
Fuel Type	**1990**	**2010**	**2015**	**2020**	**2025**	**2030**	**2035**	**2010**	**2035**	**2010-35**
Coal	450	503	484	478	466	441	417	23	19	-0.7
Oil	757	805	795	753	693	621	558	36	26	-1.5
Natural Gas	438	556	583	596	603	614	628	25	29	0.5
Nuclear	159	219	222	234	238	243	247	10	11	0.5
Hydro	23	23	25	26	26	27	28	1	1	0.8
Bioenergy	62	90	106	125	149	178	209	4	10	3.4
Other renewables	14	18	31	47	64	82	101	1	5	7.0
Total	**1,915**	**2,214**	**2,246**	**2,260**	**2,240**	**2,206**	**2,187**	**100**	**100**	**-0.0**

Source: International Energy Agency, Word Energy Outlook 2012, p. 564.

Slowing Energy Demand

This latter point bears repeating: rather than the sharply rising U.S. energy demand of the 1990 – 2010 era, the United States is now on an essentially steady-state path of aggregate energy use. This trend line therefore necessarily implies declining *per capita* energy usage, since the U.S. population is continuing to grow. Indeed, according to related historical data from the U.S. Energy Information Administration (EIA), total U.S. per capita energy use in 2035 is projected to be just *one-third* of 1980 energy-consumption levels.

Moreover, the International Energy Agency baseline forecast is that U.S. demand for coal and oil—the two primary greenhouse-gas generators—will actually decline in both aggregate as well as per capita terms between 2010 and2035, with these two fuels' share of U.S. energy use falling from 59% in 2010 to 45% in 2035. The IEA notes (p. 60) that "oil demand ends the time period 5.0 mb/d lower than 2011, at 12.6 mb/d, with the bulk of the savings arising in the transport sector, driven by improvements in fuel economy and increased use of ethanol and biodiesel… Coal use, which is constrained by relatively cheap gas and concerns over local air quality and greenhouse-gas emissions, is 17% lower in 2035 than in 2010." The use of clean natural gas, by contrast, is expected to rise in absolute terms by an average of 0.5% per year, and to increase in share from 25% in 2010 to 29% in 2035.

The Role of Renewables

A second, perhaps equally surprising, factor underlying the IEA's findings is that the projected progress toward U.S. net energy self-efficiency, while clearly benefitting from growth in the use of renewable energy resources, is only marginally dependent upon that growth. For example, while the IEA does forecast that Americans' usage of solar, wind, and other non-biological renewables will increase at a substantial compound annual rate of 7% over the term of the study, these renewables nevertheless are expected to account for only about 5% of the aggregate U.S. energy portfolio by 2035. Separately, in its 2012 Annual Energy Outlook, the EIA forecasts only a 7.7% share for biomass and other renewables by 2035, and a 10.6% share when hydropower is included (Table A1).

To be sure, according to most analysts, alternative energy sources almost certainly will represent the core of the long-term energy future for the United States and the world as a whole. But until such time that these technologies become both more economical and more efficient, the implication of the IEA's and the EIA's findings is that the burden of satisfying both U.S. and global energy needs will continue to be mostly in traditional ways, with both America's and the world's "energy gap"—the additional energy that must be produced in order to meet ongoing demand—to be filled largely by fossil fuels. As the IEA states (p. 51), "oil, coal, and natural gas will continue to meet most of the world's energy needs. Fossil fuels, which represent 81% of the primary [global] fuel mix in 2010, remain the dominant sources of energy through 2035…" Even the EIA's most optimistic scenario with respect for renewables still foresees a relatively small contribution to overall energy supply during this time period.

Advanced-Technology Oil & Gas Production

A third factor underlying the IEA's conclusions is perhaps the least expected. Rather than continuing to decline and thus driving up foreign oil imports, U.S. oil and gas production are on the upswing and are projected to continue to increase, thereby, in the IEA's words, "redefining the global energy map." As the IEA observes (p. 74), "a striking new trend now emerging is the resurgence of oil and gas production in the United States, where output had been widely assumed, even as recently as a few years ago, to be in inevitable decline.

Together with efficiency measures that are set to curb oil consumption, this energy renaissance has far-reaching consequences for energy markets, trade, and, potentially, even for energy security, geopolitics, and the global economy." The United States is even positioned to overtake oil-rich Saudi Arabia as the world's largest oil producer by as early as 2020.

The source of this increased production is equally unexpected. Despite the extensive public debate in the United States in previous decades over offshore oil drilling and the exploitation of Alaskan oil reserves, the fossil fuels that are at the heart of the recent production resurgence have resulted largely from *onshore* drilling activity in the lower 48. And most of this activity has taken place on private lands, where Federal permitting is not required and where Federal rules hence have had little effect on the growth of domestic oil production. Rather, as the IEA explains (p. 76), the impact of increased oil supply is "mainly due to the expanded production of light tight oil" from these onshore development tracts.

But there is a related and even more significant factor: both the recent and projected increases in U.S. oil and gas production result largely, not from traditional oil and gas drilling methods, but from *unconventional* production technologies. This is especially true of recent boosts in natural gas production. Says the IEA (p. 77), "the surge in unconventional gas production has been a game-changing development in North American natural gas markets…" The most prominent of these unconventional production methods is an old but recently re-emergent technique for exploiting deep-shale reserves that is commonly referred to as hydraulic fracturing, or "fracking," for short. And the story for the future is the same: the IEA projects that fully half of the global increase in natural gas production through 2035 will be due to advanced oil- and gas-extraction technologies like hydraulic fracturing.

The Challenge of Advanced Extraction Technologies

And in this fact lies the challenge posed by the new production regime. While built upon a solid and long-standing engineering foundations, advanced production techniques like hydraulic fracturing are often not well-accepted in the public domain. In fact, they have turned politically controversial, becoming perhaps the most widely criticized American energy production techniques since nuclear power and the strip-mining of coal became flashpoints in the 1970s. So intense are the feelings of many who oppose hydraulic fracturing that their condemnations often reach apocalyptic proportions, as exemplified by a November 19, 2012, article in The Nation entitled "*The Fight Against Fracking."*

> *"There's a war going on that you know nothing about between a coalition of great powers and a small insurgent movement…," author Ellen Cantarow writes of the anti-fracturing battle. "[T]he stakes couldn't be higher. Ultimately, the fate of the planet may hang in the balance…. In small hamlets and tiny towns you've never heard of, grassroots activists are making a stand in what could be the beginning of a final showdown for Earth's future."*

Other commentators are more measured in their criticism of hydraulic fracturing, but their underlying premise is the same: advanced extraction techniques like hydraulic fracturing pose immense risks for society—so much so that they cannot be considered a safe and viable source of energy, regardless of any theoretical benefits that they might offer. If this assertion is true, then the promising picture painted by the IEA for future U.S. energy supply may be little more than an illusion. For many critics of hydraulic fracturing, in fact, this is the future that they see, and their stated goal is nothing less than to block hydraulic fracturing operations wherever they take place.

Assessing Hydraulic Fracturing's Costs and Benefits

Some of the critics do have a point, as decades of on-the-ground experience have shown that there are many legitimate and important concerns regarding the potential environmental ramifications of hydraulic fracturing. But are these concerns political and substantive deal-breakers, and are their presumed negative side-effects inescapable? Or are there ways to proactively avert or subsequently mitigate any potentially adverse consequences of hydraulic fracturing? It is the purpose of this report to apply sound and objective research both to begin to answer these questions and, more generally, to assess, in a balanced fashion, the costs and benefits of the advanced-production scenario that undergirds the IEA's forecast of an energy self-sufficient America—and of a potentially more energy self-sufficient California as well.

Such dispassionate, objective analysis is essential if theoretical modeling exercises like the IEA forecast are ultimately to bear any fruit in reality. For as the IEA itself notes (p. 78), "the unconventional gas business is still in its formative years, with questions still to be answered about the extent and quality of the resource base and unsatisfied concerns about the environmental impact of producing unconventional gas. If these concerns are not addressed properly, there is the very real possibility that public opposition will halt the unconventional gas revolution in its tracks."

Implications for California

While clearly consequential from a national perspective, the IEA forecast has less obvious ramifications for California. The surge in development of natural gas through hydraulic fracturing that is at the core of the IEA's advanced-production scenario has taken place primarily in the Mid-Atlantic and Northeastern regions of the United States, and is little practiced in California. Nor, for basic geological reasons relating to the limited natural gas resources in the state, is that situation likely to change in the future.

However, California does employ hydraulic fracturing—and has done so for some time—in a different manner: for the direct, albeit relatively limited, production of oil. According to the Environmental Working Group, a Washington, D.C., based organization critical of the energy industry cited in the March 14, 2012, *Los Angeles Times*, hydraulic fracturing has been used on thousands of wells in California. But it is the future possibilities of hydraulic fracturing that have raised the technique's profile in California. As the same *Los Angeles Times* report notes, "energy companies are using the procedure to extract previously unreachable fossil fuels locked within deep rock. The industry is touting the potential of fracking to tap the largest oil shale formation in the continental United States [the Monterey Shale Formation], containing 64% of the nation's deep-rock oil deposits."

More recently, a January 2, 2013, report in the *Financial Post* notes that, on December 18, 2012, the California State Department of Conservation published draft rules "that could lead to widespread hydraulic fracturing for oil and gas" in the state. Indeed, "speaking to a conference last year, California Governor Jerry Brown, a Democrat, said he would look into issuing more permits for fracking if it could be done in a safe manner. 'I'm an optimist' that environmental concerns can be resolved, he said. 'California is the fourth-largest oil-producing state, and we want to continue that.' Issuing draft regulation could be a first step towards a big expansion of the practice."

Similarly, a February 1, 2013, editorial in the San Francisco Chronicle noted that "most Californians may not realize it, but there's a fortune buried underneath our feet. Stretching from Los Angeles to San Francisco, the Monterey Shale Formation is estimated to hold 15.5 billion barrels of recoverable oil ... By comparison, the Bakken Formation of North Dakota, which single-handedly saved that state from the effects of the recession, holds 4 billion barrels of oil." The article goes on to note that, if the resources within this shale resource were carefully and prudently developed, "Californians could be bidding their budgetary woes goodbye" and, moreover, that the State "has an opportunity to become a pioneer in the safe use of hydraulic fracturing through appropriately designed regulations."

It is in this connection that at least the theoretical implications of hydraulic fracturing for California become clear. If the promise of hydraulic fracturing of oil is a valid one, then California may have a much greater resource base of readily exploitable oil than has previously been assumed. If so, just like the United States as a whole, California might well be standing on the threshold of an energy boom—one that might even overshadow the oil and gas boom of the upper Midwest and Northeast.

California's Economic Challenges

That is the theory anyway—one that, as noted above, ultimately could be upended by unmet concerns over the potentially adverse environmental concerns of advanced oil-extraction techniques like hydraulic fracturing. But setting aside these concerns for the moment and looking only at the geologically rooted theory, does this possibility really even matter? Is there a legitimate reason why Californians would be willing even to entertain the not-yet-fully-understood risks of an advanced oil-extraction technologies in the development of the Monterey Shale?

There may well be reasons, from both a political and practical perspective, for entertaining this concept. As noted earlier, California has faced serious economic challenges in recent years. A combination of adverse economic conditions have imposed tough choices on State and local political leaders, even while these problems have undermined living standards and the quality of life for many Californians. Initiatives that could strengthen California's economy and enhance its ability to create jobs and produce higher incomes for the State's residents certainly would be welcome to jobseekers, businesses, governments, and political leaders alike. A key question that motivates this study, then, is this: is such an economy-boosting development in sight?

Energy and California's Economy

There may well be such an engine emerging—and it lies within the State's own base of energy resources. This connection, of course, is nothing new, as energy and economic growth have long been linked in California (and nationally as well). The November 2011 report "Powering California: Assessing California's Energy Future" synthesized the research of leading government and academic institutions in California and nationwide, including the California Energy Commission and the U.S. Energy Information Administration. The report, authored by The Communications Institute, a Los Angeles-based research center, described the relationship between energy and economics within the State in this way: "Another related but important question turns on the economics of the energy sector. Specifically: could the accelerated development of California's indigenous energy supplies speed the growth of California's economy, add jobs to our State, and enhance State tax revenues? Such questions are particularly important as California struggles to emerge from one of its most difficult fiscal crises in memory. Answers to these and other vital questions will illuminate our understanding in these key areas. But more than that, they also will help us to make more informed, more intelligent, and—ultimately—more beneficial public policy decisions for our people, for our businesses, and for our State."

According to media reports, California appears to be pursuing energy policies that, at least in part, fail to fully take advantage of these potential economic benefits. As a December 7, 2012, analysis in *The Daily Beast* notes, “California, whose Monterey Formation alone is estimated to be four times larger than North Dakota’s Bakken reserve, has chosen… to sharply limit its fossil-fuel industry. As a result, it has generated barely one-tenth the [200,000] new fossil-fuel jobs [that have been produced] in archrival Texas. Not surprisingly, California… [also has] lagged behind in GDP and income growth, while the energy states have for the most part enjoyed the strongest gains.”

Chapter 3 of this report will explore the relationship between energy and economics in California in greater detail. First, however, we need to establish the context in which such a discussion inevitably will play out—and why greater within-state energy production might be desirable to California. That pursuit takes us back into the realm of the California energy landscape.

California Energy Demand

Understanding the relationship between energy and economics within California necessarily begins with an appreciation of California’s energy picture—specifically, the current levels of energy demand and supply within the State, and the expected future course of these variables. It is to that set of issues that we turn first.

Current California Aggregate Energy Demand

One of California’s greatest success stories in dealing with energy demand has been the State’s successful conservation initiatives over the past few decades. According to the most recent data from the U.S. Energy Information Administration, Californians are using 217 million Btu of energy per capita each year. That sounds like a great deal of energy use—and it is. However, although California has long had a reputation as an intensive energy user, the facts tell a markedly different story. The State actually ranks 47th out of 50 states in per capita energy usage. Wyoming and Alaska, which ranked #1 and #2 in per capita energy use, respectively, consume almost four times as much energy per capita as California does. In fact, California’s per capita energy use is almost 30% lower than the U.S. average, owing, of course, in part to its relatively milder climate.

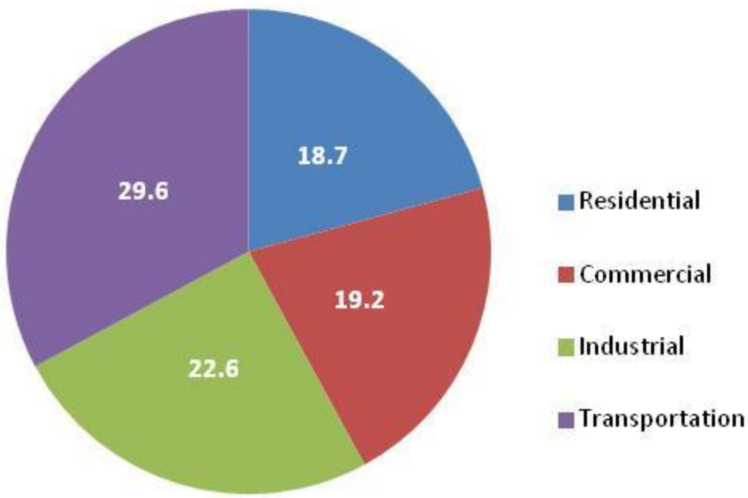
Considered in the aggregate, Californians annual usage of 8,006 trillion Btu of energy represents only 8.6% of total U.S. energy consumption, despite the State’s accounting for 12.4% of the total U.S. population. Petroleum consumption in California is only slightly higher, with California accounting for 9.6% of all U.S. petroleum usage. For motor-vehicle gasoline, not surprisingly, the automobile-dependent State’s energy usage is relatively higher, accounting for 10.9% of the U.S. total. While California’s natural gas consumption is in a similar range of 9.6% of the U.S. total, California’s direct coal usage within its borders is markedly lower, representing just 0.2% of all coal consumed in the United States (thought the state currently imports significant amounts of coal-fired electricity generation form other states).

Current California Energy Demand by Sector

As in other states, there are four principal energy-consuming sectors in California: residential, commercial, industrial, and transportation. While the distribution of energy usage among sectors is similar in many respects to what takes place in other jurisdictions, there are a number of aspects of the demand for energy by sector that are more or less unique to California. One of the most obvious of these unique characteristics is that the largest end-user of energy in California is transportation.

According to the EIA, fully 29.6% of California's energy is consumed by the transportation sector. Residential, commercial, and industrial usages are all at significantly lower levels, accounting for between 18.7% and 22.6% of the State's energy use (see Chart 1).

Chart 1. Current California Energy Demand by Sector



Source: U.S. Energy Information Administration.

Looking at the sources of energy consumed in each sector highlights significant variations in the type of energy used by sector. Specifically, according to the EIA's 2012 Annual Energy Outlook (Table 2):

- **Residential sector.** Natural gas provides 84.7% of the California residential sector's energy use, with petroleum accounting for 5.6%, biomass for 4.3%, and other renewables for 4.3%

- **Commercial sector**. As with the residential sector, natural gas accounts for the largest share of the California commercial sector's energy use—75.9%. Petroleum is responsible for 10.6% of energy use, biomass for 2.8%, and other renewables for 10.6%.

- **Industrial sector**. Natural gas is responsible for 61.9% of energy consumption in the California industrial sector, with petroleum responsible for 22.3%. Coal accounts for 2.6% and biomass for 2.2%.

- **Transportation sector.** In contrast to the situation in other sectors, petroleum accounts for 99.2% of energy used in California's transportation sector and natural gas just 0.8% of energy use.

Table 2. California Energy Demand by Sector and Source, 2010 (Percent of Total)

	Residential	Commercial	Industrial	Transportation
Petroleum	5.6	10.6	33.3	99.2
Natural Gas	84.7	75.9	61.9	0.8
Coal	0.0	0.0	2.6	0.0
Nuclear	0.0	0.0	0.0	0.0
Hydroelectric	0.0	0.0	0.0	0.0
Biomass	4.3	2.8	2.2	0.0
Other Renewables	5.4	10.6	0.0	0.0
Total	**100.0**	**100.0**	**100.0**	**100.0**

Source: U.S. Energy Information Administration, Table A1.

Future California Energy Demand

Although the International Energy Agency foresees slowing energy demand in the medium- and long-term for the United States as a whole, other studies come to a different conclusion for California. For instance, according to a November 2009 report by the research group Energy and Environmental Economics, Inc. (E Three), entitled "*Meeting California's Long-Term Greenhouse Gas Reduction Goals*," total California energy usage, based on the group's mid-tier forecast, is expected to grow from 6.10 quadrillion Btu (quads) in 2008 to 9.93 quads in 2050. This usage volume represents an increase of 63% over the 42-year period, or an average annual increase of 1.2%. This projected growth in energy use is close to California's forecast population growth rate of from 1.0% per year through 2025 (California Energy Commission) to 1.3% per year through 2025 (University of California, Davis), but is well below the projected growth rates for the State's economic output of from 2.7% to 3.4% per year through 2025 (California Energy Commission), suggesting continued efficiencies in the State's use of energy.

Likewise, the California Council on Science & Technology, in a May 2011 report that examined ways of reducing greenhouse-gas emissions within the State, came to this conclusion: "By 2050," the Council wrote, "California's population is expected to grow from the 2005 level of 37 million to 55 million. Even with moderate economic growth and business-as-usual (BAU) efficiency gains, [California] will need roughly twice as much energy in 2050 as we use today." The Council's forecast implies an average annual increase in statewide energy usage of approximately 1.6%, only somewhat more aggressive than the E Three estimate.

In sum, then, California remains a national leader in energy conservation and implementation of energy-efficient technologies and practices, and continuing improvements can be anticipated in each of these areas. That said, largely because of ongoing population and economic growth, energy use within the State can be expected to rise by between 1.0% and 1.6% per year over ensuing decades, and—by 2050—the State can be expected to require from 63% to 100% more energy than it does at present. This figure constitutes California's own future "energy gap." California's political and economic leaders therefore need to ask themselves: what are the most productive, economically efficient, and environmentally protective ways of securing that additional energy necessary to fill that energy gap? And: is there any scenario in which hydraulic fracturing-based production of oil within the State can play a meaningful role?

California Energy Supply

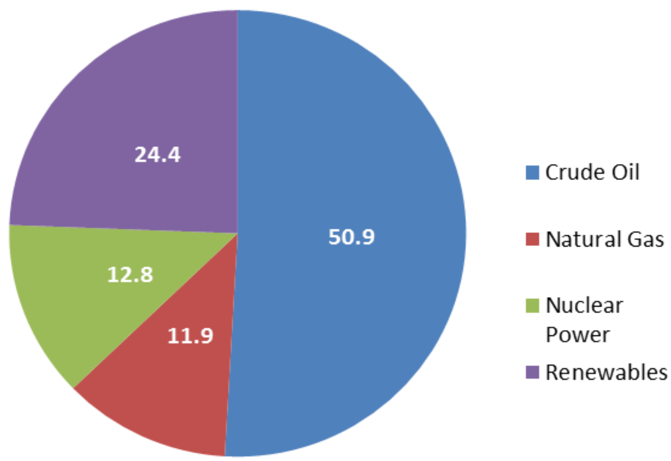
Current California Energy Supply

Answers to the above questions begin with an examination of the current state of California's energy economy. California's current energy portfolio bears both similarities to and differences from the energy portfolios of other states. Like most other states, California obtains the majority of its energy from oil and natural gas. California, however, receives a much higher proportion of its energy from renewable resources (mostly hydroelectric power), and a much lower percentage (almost zero) from coal, which is a dominant resource in many other states. (Note that most of these latter resources are used primarily in the generation of electricity, and have little direct impact on energy supplies in the transportation sector.)

In total, according to the U.S. Energy Information Administration's 2012 Annual Energy Outlook, California's current energy supply is as follows (see Chart 2):

- Crude oil, 50.9%
- Natural gas, 11.9%
- Nuclear power, 12.8%
- Coal, 0.0%
- Renewables, 24.4%

Chart 2. Current California Energy Supply by Type

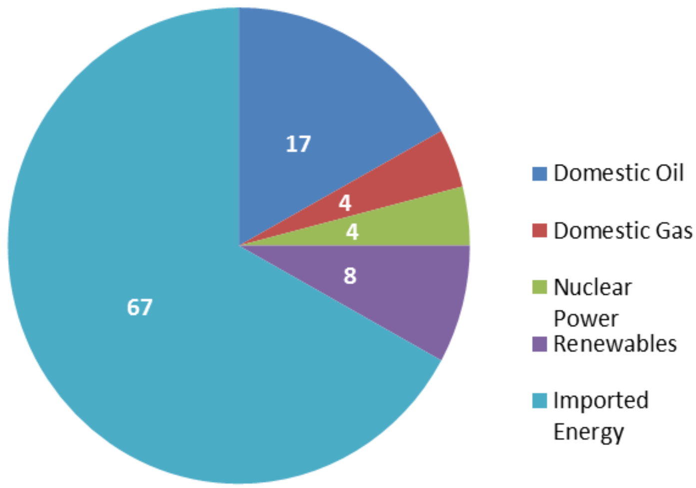


Source: U.S. Energy Information Administration.

Looked at in terms of in-state production versus imported energy, however, the breakouts paint a markedly different picture, wherein imports of energy of various types play the dominant role (see Chart 3). Specifically:

- 17% from domestically produced crude oil.
- 4% from domestically produced natural gas.
- 4% from nuclear power.
- 8% from renewables (primarily hydroelectric power).
- 67% from imports (primarily crude oil, natural gas, and electricity).

Chart 3. Current California Energy Supply by Source



Source: U.S. Energy Information Administration.

California's Energy Potential

One question that immediately arises from the above analysis is this: why does California currently import so much of its energy requirements? It isn't because of the lack of reserves. As the EIA writes, "California is rich in both conventional and renewable energy resources. It has large crude oil and substantial natural gas deposits in six geological basins, located in the Central Valley and along the Pacific coast… Seventeen of the Nation's 100 largest oil fields are located in California, including the Belridge South oil field, the third largest oil field in the contiguous United States." In addition, in reviewing studies by the EIA and other researchers, the November 2011 "Powering California" report noted that "California has the largest untapped potential for additional oil and gas production in the United States… Offshore, California contains more than 10 billion barrels of oil and nearly 12 trillion cubic feet of natural gas. Onshore, the Monterey Shale may contain more than 15 billion barrels of oil."

Nor is California's need to import so much of its energy due to a lack of processing capability. Again, according to the EIA, "California ranks third in the United States in petroleum refining capacity and accounts for more than one-tenth of total U.S. capacity. California's largest refineries are highly sophisticated and are capable of processing a wide variety of crude oil types and are designed to yield a high percentage of light products like motor gasoline. To meet strict Federal and State environmental regulations, California refineries are configured to produce cleaner fuels, including reformulated motor gasoline and low-sulfur diesel."

Finally, California's energy imports do not arise from a failure to exploit alternative energy. The EIA report documents that "California is one of the largest hydroelectric power producers in the United States, and with adequate rainfall, hydroelectric power typically accounts for close to one-fifth of State electricity generation. California's two nuclear power plants account for about 17% of total generation… California leads the Nation in electricity generation from non-hydroelectric renewable energy sources… California is the top producer of geothermal energy in the nation with more than 2,500 megawatts of capacity. A facility known as 'The Geysers,' located in the Mayacamas Mountains north of San Francisco, is the largest complex of geothermal power plants in the world, with more than 700 MW of installed capacity. California is also a leading producer of wind energy and holds nearly 10% of the nation's capacity. The world's largest solar power facility operates in California's Mojave Desert."

And yet the point remains: California is becoming less and less able to satisfy its energy demand with domestically generated energy supplies. The EIA explains: "California refineries have become increasingly dependent on foreign imports. Led by Saudi Arabia, Iraq, and Ecuador, foreign suppliers now provide more than two-fifths of the crude oil refined in California..." Moreover, "California natural gas production typically accounts for less than 2% of total U.S. production and satisfies less than one-fifth of State demand." And, "due [in part] to high electricity demand, California imports more electricity than any other state."

California's Declining Energy Production

If the source of California's growing energy imports does not lie with limited reserves, limited capacity, or the failure to pursue alternative energy, then from what source comes the problem? The primary explanation for this phenomenon is clear: *declining in-state energy production.* Notwithstanding the State's enormous energy potential, California's development of its indigenous energy resources (particularly its oil resources) actually has been declining in recent years.

On May 11, 2011, an important report was released by the California Energy Commission, entitled "*Crude Oil Import Forecast & HCICO Screening*. This report along with an earlier CEC report, "*Outlook for Crude Oil Imports into California*" (July 12, 2007), confirmed, California crude production had declined by 47% between 1985 and 2010, with onshore production having fallen by more than half. As a result, foreign crude oil imports into California had increased by some 16% per year between 1986 and 2006, and somewhat less thereafter, such that crude oil imports in 2010 were more than 71% greater than the levels of 2000 and more than five times greater than they were in 1985.

Unfortunately, the future does not look much brighter. The Los Angeles Economic Development Corporation (LAEDC), in a 2008 study, projected that, from 2005 to 2019, the processing of crude oil by California refineries was expected to increase from 1.8 million barrels per day (mbd) to 2.3 mbd. The study forecast that the sources of this oil, however, would shift dramatically over this time period. In particular, crude oil pumped in-state was expected to decline from 696,000 barrels per day (bpd) to 423,000 bpd, while the State's reliance on imports was expected to more than double over this time, rising from 737,000 bpd to 1.87 million bpd. The LAEDC pointed out that "The decline of in-state production is particularly important because it means California will have to import an additional 273,000 bpd of crude oil even if demand were to remain constant—which it obviously will not do."

Figures from the California Energy Commission (CEC) corroborate these findings. In its August 2011 "*Transportation Energy Forecasts and Analyses for the 2011 Integrated Energy Policy Report*" report, the CEC writes (p. 14) that "California's annual crude oil production was approximately 224 million barrels during 2010, averaging approximately 613,000 barrels per day." This decline in California crude oil production "has continued since 1985, when crude oil production peaked at 424 million barrels per year." Thereafter, while production in Alaska declined by 67.2% and that in the rest of the United States by 28.2%, California crude oil production declined by 47.2%. Nor, again, is the future much more promising. According to the CEC, "California crude oil production is forecast to continue declining at a rate of between 2.2% and 3.1% per year" throughout at least 2030. However, these forecasts for California do not consider the great potential of oil deposits within the State that are recoverable with advanced oil-extraction technologies.

The Role of Renewables

One might hope that increasing reliance on renewables—especially given California's Renewable Portfolio Standard (RPS), which requires that, by 2020, 33% of the State's electricity be generated from renewable resources—could help to fill this production gap. And, indeed, the raw figures are impressive. In California, in the EIA's baseline forecast, production of electricity from renewables is projected to grow from 54.4 billion kilowatt hours (bkWh) in 2010 to 94.89 bkWh in 2035, for a growth rate of 74.3% over the 25-year period.

The proportional gains that the EIA projects for individual renewable technologies vary but, in general, are quite high as well. For instance, while electricity generation from hydropower grows only by 28.2% and from biomass only by 1.7% in the baseline case over this period, the respective growth figures for other renewable sources are much greater. Specifically:

- For geothermal, 252%.
- For solar thermal, 127%.
- For solar photovoltaic, 850%.
- For wind, 44.7%.

Encouraging as these figures are, however, they mask a critical fact: in California (as elsewhere), renewable energy sources like those just referenced are used predominantly in the production of electricity, with some collateral usage in the residential, commercial, and industrial sectors. Specifically, according to the EIA, 82.0% of California's combined total of hydroelectric, biomass, and other renewable resources currently goes into the production of electricity. Some 8.0% is used in the residential sector, 6.2% in the commercial sector, and 3.8% in the industrial sector. By contrast, essentially zero percent of these resources are used in the oil-dependent (and, to a much lesser degree, natural gas-dependent) transportation sector.

Hence, the disconnect. Unlike the United States as a whole, California's energy needs are unlikely to diminish over the next few decades, and that assessment is particularly true for the State's transportation sector—a sector that currently relies heavily on petroleum products, with only limited (though growing) reliance on natural gas. And yet it is precisely in the petroleum sector where California's decline in in-state energy production is most pronounced. While the production and use of renewable energy sources like hydroelectric, geothermal, solar, and wind power is growing strongly in California, these renewables cannot substitute for the use of oil and natural gas in vehicles, and so the growth in their use will have negligible effect on the State's ability to meet the increasing demand for energy in its transportation sector.

Hydraulic fracturing, by contrast, is employed in California primarily for the production of oil from the State's immense shale reserves. Hydraulic fracturing therefore offers at least the prospect of helping to offset the decline in more traditional forms of in-state oil production, and hence of countering the State's growing need for oil imports. As such, hydraulic fracturing could immediately help to satisfy the energy needs of California's transportation sector in a way that the previously listed renewable energy sources, despite their broader promise, could not. Whether California should pursue a more aggressive hydraulic fracturing effort, of course, remains an entirely different question. But it is in the above context, devoid of significant alternative means for filling California's growing petroleum needs, in which all the costs and benefits of hydraulic fracturing must be evaluated.

Transportation Sector Forecasts

The above discussion documents trends in California's energy picture overall, and those trends appear to establish at least an arguable case for greater in-state production of petroleum, possibly through more aggressive advanced-technology drilling activities like hydraulic fracturing. Such enhanced production would be intended primarily to serve the needs of California's highly petroleum-dependent transportation sector. But are there developments within that sector itself that might ameliorate or even eliminate the value of increased in-state petroleum production? We turn finally to that question.

The California Energy Commission is required by State Senate Bill 1389 to conduct "assessments and forecasts of all aspects of energy industry supply, production, transportation, delivery and distribution, demand, and prices to develop policies for its Integrated Energy Policy Report." The CEC's August 2011 release, "Transportation Energy Forecasts and Analyses for the 2011 Integrated Energy Policy Report," provides a detailed overview of both current and future energy supply and demand in California's transportation sector. We highlight some of those findings to enable us to better assess the need for enhanced petroleum production in California.

Gasoline Supply & Demand

According to the CEC (p. 15), California is in the midst of a long-term secular decline in per capita gasoline consumption. Specifically, "California per capita gasoline consumption fell from 1.36 gallons per day in 1990 to 1.04 in 2010, a 23.5% decrease." The first decade of this decline was due largely to an increase in vehicle efficiency; however, the second decade's decline in gasoline consumption resulted primarily from reductions in per capita vehicle miles traveled, largely because of higher gasoline prices. On an overall basis, because of growing in-state population, California's total gasoline consumption edged up in 2010 by 0.2% from 2009 levels, rising from 40.6 million gallons per day in 2009 to 40.7 million gallons per day in 2010.

For the future, the CEC foresees a range of gasoline demand levels that encompass either slight reductions in demand or else slight increases in demand. For gasoline demand overall—and in the absence of regulatory changes—the CEC projects (p. 75) that, in its Low Petroleum Demand Scenario, total California gasoline usage will fall by a compound average annual rate of 0.23% per year, from 14.8 billion barrels per year in 2009 to 14.1 billion barrels per year in 2030—an overall decline of 4.8%. By contrast, in its High Petroleum Demand Scenario, the Commission foresees demand growing to 16.9 billion barrels per year, or a compound average annual growth rate of 0.64%—and an overall increase of 14.3%. (The compound average annual growth rates for light-duty vehicles only are 0.75% and 0.79% lower than for total gasoline usage, respectively.)

These figures, then, suggest that historical trends in gasoline demand in California are not likely to change markedly in the near- and medium-term. While there is a possibility that overall demand may decline slightly, there is also the possibility that it will continue to grow. Indeed, in its High Petroleum Demand Scenario, the CEC expects that growth in gasoline demand to accelerate over time, from an annual growth rate of 0.16% in 2015, rising to an annual growth rate of 1.08% by 2030, or nearly seven times as great. (Even in the Low Petroleum Demand Scenario, the projected annual growth rate increases from negative 0.37% in 2015 to positive 0.23% in 2030.)

The Impact of Alternative Fuel Types

One of the most important factors placing downward pressure on the demand for gasoline in California is the ongoing growth in non-petroleum additives to petroleum-based gasoline. The most prevalent of these fuel additions is ethanol, and one of the fastest growing formulations is an 85% ethanol blend referred to as E85. In the absence of regulatory changes, the CEC (p. 3) foresees E85 usage climbing from 13.2 million gallons in 2009 to 48.8 million gallons in 2030 under the Low Petroleum Demand Scenario—a growth of nearly four times. In the High Petroleum Demand Scenario, E85 consumption is projected to soar to 64.3 million gallons—a growth of nearly five times. These obviously are significant growth rates. Yet even in this most optimistic scenario, E85 consumption nevertheless represents about only 0.4% of State gasoline consumption by the year 2030—a contribution that, while quite helpful to the State's energy portfolio and environmental-protection efforts, will have only marginal effects on the transportation sector's need for petroleum products.

The Impact of Alternative Vehicle Types

Beyond adding ethanol and other non-petroleum additives to gasoline, Californians have led the nation in the purchase and use of non-gasoline-powered and other alternative vehicles. For instance, according to California Department of Motor Vehicles data analyzed by the CEC (p. 48):

- Hybrid vehicle usage has grown at a compound annual rate of 66.2% over the past decade, rising from 6,609 vehicles in 2001 to 384,567 vehicles in 2009.
- Flex fuel vehicle usage has grown at a compound annual rate of 19.6% over this same period, rising from 97,611 vehicles in 2001 to 409,636 in 2009.
- Electric vehicle usage has risen at a compound annual rate of 22.8%, climbing from 2,905 vehicles in 2001 to 15,031 in 2009.
- And natural gas vehicle usage has grown at a compound annual rate of 29.8%, jumping from 2,082 in 2001 to 24,819 in 2009.

Despite these impressive double-digit growth rates, however, the population of alternative vehicles on California's roads in 2009—a total of 834,053 vehicles—represents only 3.1% of California's vehicle fleet, and pales in comparison to the 25.2 million gasoline-powered vehicles (with an additional 462,936 diesel-powered vehicles).

This situation, however, is projected to fundamentally change over medium-term. In its High Petroleum Demand Scenario, the CEC foresees (p. 73) a total of approximately 16.7 million alternative vehicles on California's roads by 2030, as compared with approximately 24.0 million gasoline-powered vehicles—truly significant market penetration. Nevertheless, because even many of these alternative vehicles use at least some gasoline and because they may be driven less than more traditional gasoline or diesel vehicles, their contribution to the reduction in gasoline demand in California, as noted in the discussion of aggregate gasoline demand, above, appears to be modest at best.

The Impact of Regulation

Both California and the Federal government have long used regulatory authority as a means of promoting more environmentally prudent energy use. The California Renewable Portfolio Standard, which governs electricity production within the State, is one such regulatory instance within California. Another regulatory initiative, the Federal Renewable Fuel Standards 2 (RFS2), applies specifically to vehicular fuel usage. As the CEC explains (p. 4), "the revised Federal Renewable Fuel Standards will require more renewable fuels, primarily ethanol and, to a lesser extent, biodiesel."

According to CEC estimates, under its Low Petroleum Demand Scenario for gasoline, "the final forecast of total ethanol demand in California rises from 1.5 billion gallons in 2010 to 2.7 billion gallons by 2020." Likewise, under its High Petroleum Demand Scenario for gasoline, "the final forecast of total ethanol demand in California rises about the same," from 1.5 billion gallons in 2010 to 2.7 billion gallons by 2020.

Nevertheless, despite these gains, overall California gasoline demand is only modestly affected. In the CEC's Low Petroleum Demand Scenario, taking the RFS2 requirements into account (p. 77) lowers 2030 annual gasoline demand from a projected 14.1 billion gallons to a projected 11.7 billion gallons—a relatively significant reduction of 17.0%. However, in the CEC's High Petroleum Demand Scenario, the falloff in annual gasoline demand is from 16.9 billion gallons to just 15.3 billion gallons, a decline of only about 9.5%.

Conclusion

Even with the projected growth in California's use of energy, the State appears to have ample reserves either within its boundaries or offshore in order to meet this demand. However, the development of conventional energy reserves within the State (and particularly conventional oil reserves) actually has declined in recent years. Alternative energy resources, while promising some relief in this area, are likely to have only a modest impact on statewide energy supplies through 2030, particularly in the petroleum-dependent transportation sector. Previously, the California economy had benefited from its comparative economic advantage in the production and export of energy, but that advantage eroded in recent decades as local supplies became relatively more expensive in comparison to external supplies. Yet the pendulum can swing back, and the possibility of developing shale oil at comparatively low cost may allow the State to return to a position of using more in-state energy resources in contrast to importing them.

Of course, California has been rightly aggressive in acting to protect its unique and precious environmental heritage. This commitment to environmental protection must be maintained. Within that context, however, Californians now need to confront a new challenge: how the State can undertake the scientifically-informed and environmentally sensitive energy-development efforts that it needs in order to promote economic growth, jobs creation, the enhancement of government revenues, and Californians' overall quality of life, even as it continues to protect and preserve the environment.

The prudent development of California's deep-shale resources, which the State possesses in abundance, may be one possible answer to this dilemma—as the IEA report discussed at the beginning of this section affirms. At the same time, shale in general and the California shale product in particular have known and possibly unanticipated environmental consequences—consequences that must be well-understood and proactively dealt with, as even most in the shale-development industry itself recognize.

At this point, we do not know precisely what forms of environmental protection and mitigation are necessary or even possible in order to allow for deep-shale production in California that adheres to the highest of environmental standards. We also do not know exactly how much oil may be producible from California's shale, nor at what cost—nor what the short- and long-term economic benefits, if any, may be. These are vital questions that must be objectively and scientifically assessed, and it is to this matter that we now turn.

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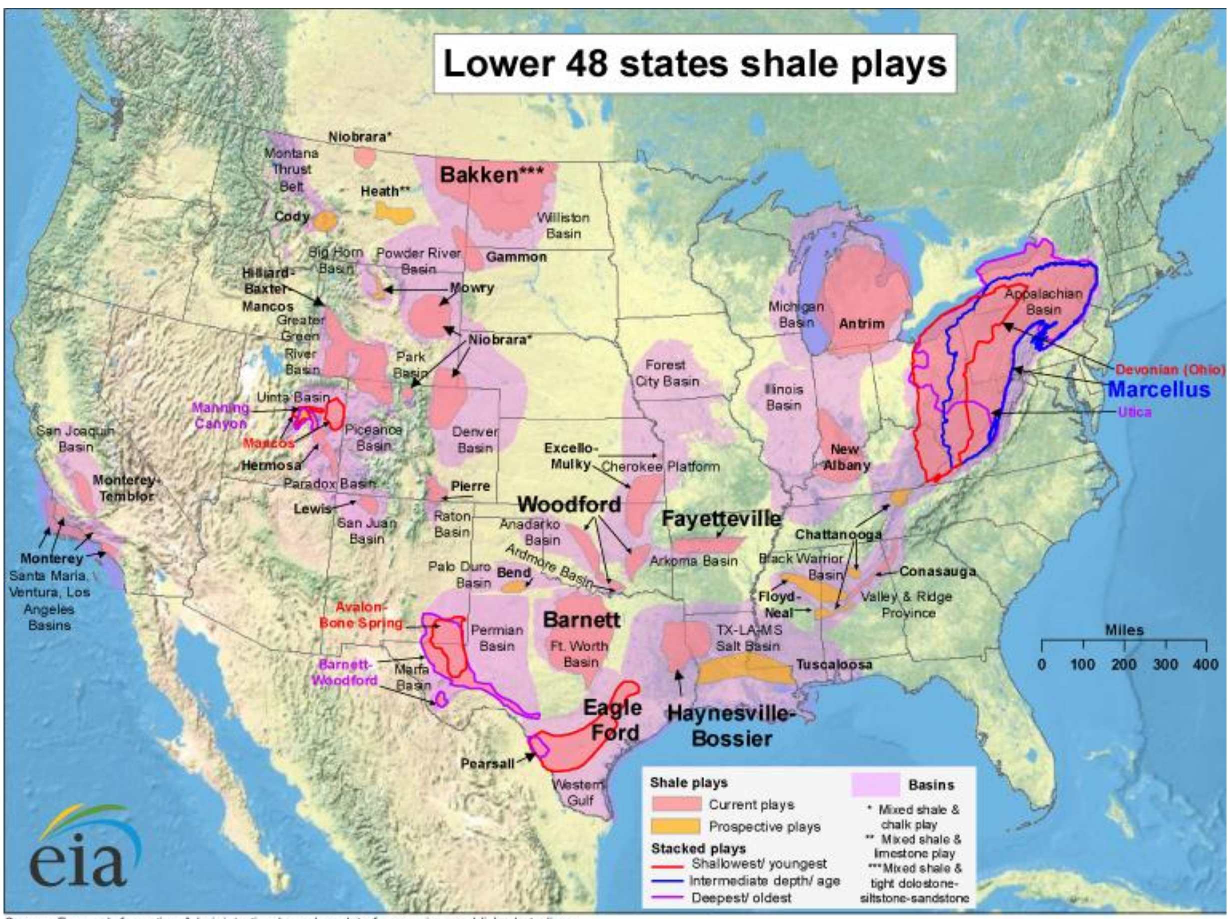
Chapter 3. Macroeconomic Impacts of Developing The Monterey Shale Using Advanced-Extraction Technology

By JiYoung Park and Peter Gordon[1]

Our purpose is to estimate the macroeconomic impacts of expanded advanced-technology oil drilling in California—particularly, in the Monterey Shale Formation (see Figures 1 and 2).[2] Describing economic impacts some years into the future is challenging and requires great care. We project California GDP per capita for selected years, to 2030, under various Monterey Shale oil production scenarios. From GDP per capita, we estimate impacts on jobs, personal income, and tax collections. Our approach is to estimate economic growth models that use available data and credible econometric methods.

Figure 1. U.S. shale formations, including the Monterey Shale Formation



Source: Energy Information Administration based on data from various published studies.
Updated: May 9, 2011

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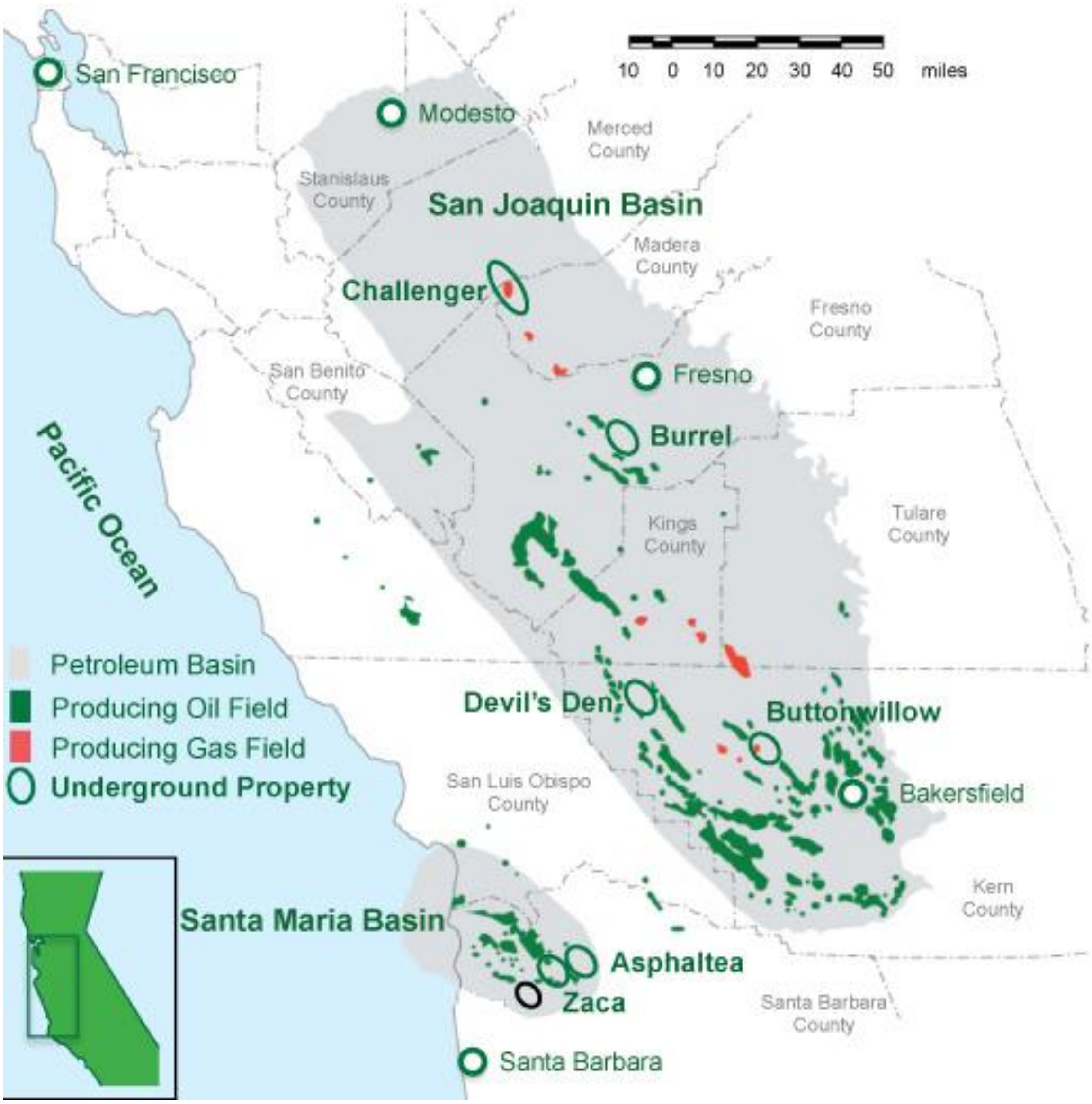
[1] Appendix K of this report is done by Dr. Dan Wei, a research professor at USC Price School of Public Policy (working with Prof. Rose) and Arman Khodabakhnejad, a Ph D student (under Prof. Fred Aminzadeh) at USC Viterbi School of Engineering.

[2] Impact studies must be distinguished from full-blown cost-benefit analyses. Here, we only address a subset of possible benefits and do not evaluate any of the costs.

Figure 2. The Monterey Shale Formation in California



Source: Underground Energy (ugenergy.com).

Economic booms from new oil and gas drilling have recently been experienced in various states. These are a matter of record and we seek to learn from them. What if California experiences similar drilling opportunities—particularly, with regard to the oil locked underground in the Monterey Shale Formation? What would be the economic effects? Generally speaking, there are two parts to our approach. First, we consider alternate Monterey Shale multi-year oil-drilling scenarios to 2030 (base case vs. high and low enhanced-drilling scenarios); second, we seek to simulate how the California economy might respond by studying the experience of the recent oil-boom states. The economic impacts in the oil-boom states have been widely reported and are significant. In neither case we do not address many technical and environmental challenges associated with exploration and production of Monterrey shale. See Brown (2012a and b) where some of these issues are addressed.

Overview of Results

The main results of our work are shown in Table 3 (and elaborated, with high and low estimates, in Tables 12.1.a-12.2.b below), reporting the most conservative path, which involves what we call the "North Dakota" scenario—which involves the most moderate expansion of the oil-boom states for the years for which we have all of the required data to 2010—thereby excluding the most recent years of North Dakota's boom (Figure 4). These simulations employ alternative Monterey Shale oil-drilling possibilities developed in Appendix K of this report and summarized in Table 8.

The two enhanced-drilling cases involve a low "Adapted EIA advanced-technology oil drilling scenario" and a high "Projected advanced-technology oil well drilling scenario." For the low enhanced-drilling case, key California economic variables grow by between 0.8 percent (196,200 new jobs;) and 4.3 percent, (1,206,700 jobs), depending on the forecast year. (Note that all model results include the economic impacts on *all* sectors, not just the oil and gas sector.) For the high enhanced-drilling case, the possible effects are much greater, ranging from 4.2 percent (827,700 new jobs) to 22.4 percent (4,425,000 new jobs).

But because modeling extraordinary impacts is always a challenge, precise forecasts are not feasible; instead, we are interested mostly in *patterns* of development. It therefore makes the most sense to emphasize a set of median (half-way) scenario results. That scenario suggests 512,000 to 2,815,800 new jobs as shown in the last column of Table 3.[3] This represents an increase in the number of jobs in the State of from 2.1% to 10.0%.

We also should be mindful that the North Dakota experience shows that an oil boom can prompt significant in-migration of labor. In just the one year ending July 1, 2012, for instance, North Dakota's population grew by 2.17 percent while the overall U.S. population grew by only 0.75 percent. Therefore, should these scenarios evolve as described, California not only would likely gain a significant number of jobs, but would experience nontrivial population growth as well.

There are other important economic effects as well. For instance, in the median case, depending upon the year:

- State per-capita gross domestic product (GDP) grows by $1,600 to $11,000, or by 2.6% to 14.3%

- Personal income grows by $40.6 billion to $222.3 billion, or by 2.1% to 10.0%.

- State & local government revenues (tax collections) grow by $4.5 billion to $24.6 billion, or by 2.1% to 10.0%.

[3] "Jobs created" are not necessarily a measure of economic benefits. Labor is essentially a cost of production. Nevertheless, in times of high unemployment, most people welcome the prospect of more job opportunities.

Table ES1. Overview of Incremental California Economic Impacts

	Year	Baseline	Increment
Per Capita GDP ($) The amount of economic activity within the state, divided by the number of people in the state	2015	62,000	1,600
	2020	72,000	10,300
	2025	82,000	11,000
	2030	93,000	8,300
Employment (jobs) The total number of people employed in the state	2015	24,329,100	512,000
	2020	28,253,200	2,815,800
	2025	32,177,200	2,652,800
	2030	36,493,700	1,770,900
Personal Income ($ millions) The total of all income earned by all people within the state	2015	1,928,600	40,600
	2020	2,239,700	223,200
	2025	2,550,700	210,300
	2030	2,892,900	140,400
Tax Collections ($ millions) Tax revenue (tax collections) by state, local, & county government	2015	212,900	4,500
	2020	247,300	24,600
	2025	281,600	23,200
	2030	319,400	15,500

Notes: 1. Median drilling case indicates the economic increment from baseline values of that year.
2. Values are rounded and elaborated in Tables 12.1.a-12.2.b.
3. Baseline values are values that would exist in the absence of accelerated shale-oil development.
4. Incremented values are additions to baseline values that result from accelerated shale-oil development.

As demonstrated in Figure 3, we link: (i) California oil production; (ii) the oil/gas extraction industry component of California GDP (oil and gas are combined in the GDP accounts; this variable is sensitive to oil and gas price as well as quantity effects); and (iii) the *net* California GDP per capita, e.g., the portions of GDP that exclude oil/gas extraction. We conducted analysis for California as well as three oil boom states: North Dakota, Wyoming and South Dakota. These three states have recently experienced the effects of a significant oil drilling boom. Our state-level GDP data only go to 2010, but the North Dakota boom has expanded since then. Also, there is population growth evidence that the boom in these states has accelerated since 2010, almost doubling between 2010 and 2012 (see Figure 4 and Tables 4.1 and 4.2 for North Dakota's more recent performance).[4] The more recent years of North Dakota's experience show what can occur if enhanced drilling came to pass, including substantial in-migration of properly skilled workers. Finally (iv) we estimate California personal income, employment and tax collection impacts from our forecast of nominal per capita California GDP.

[4] http://www.census.gov/newsroom/releases/archives/population/cb12-250.html.

Figure 3. Full economic impact model structure

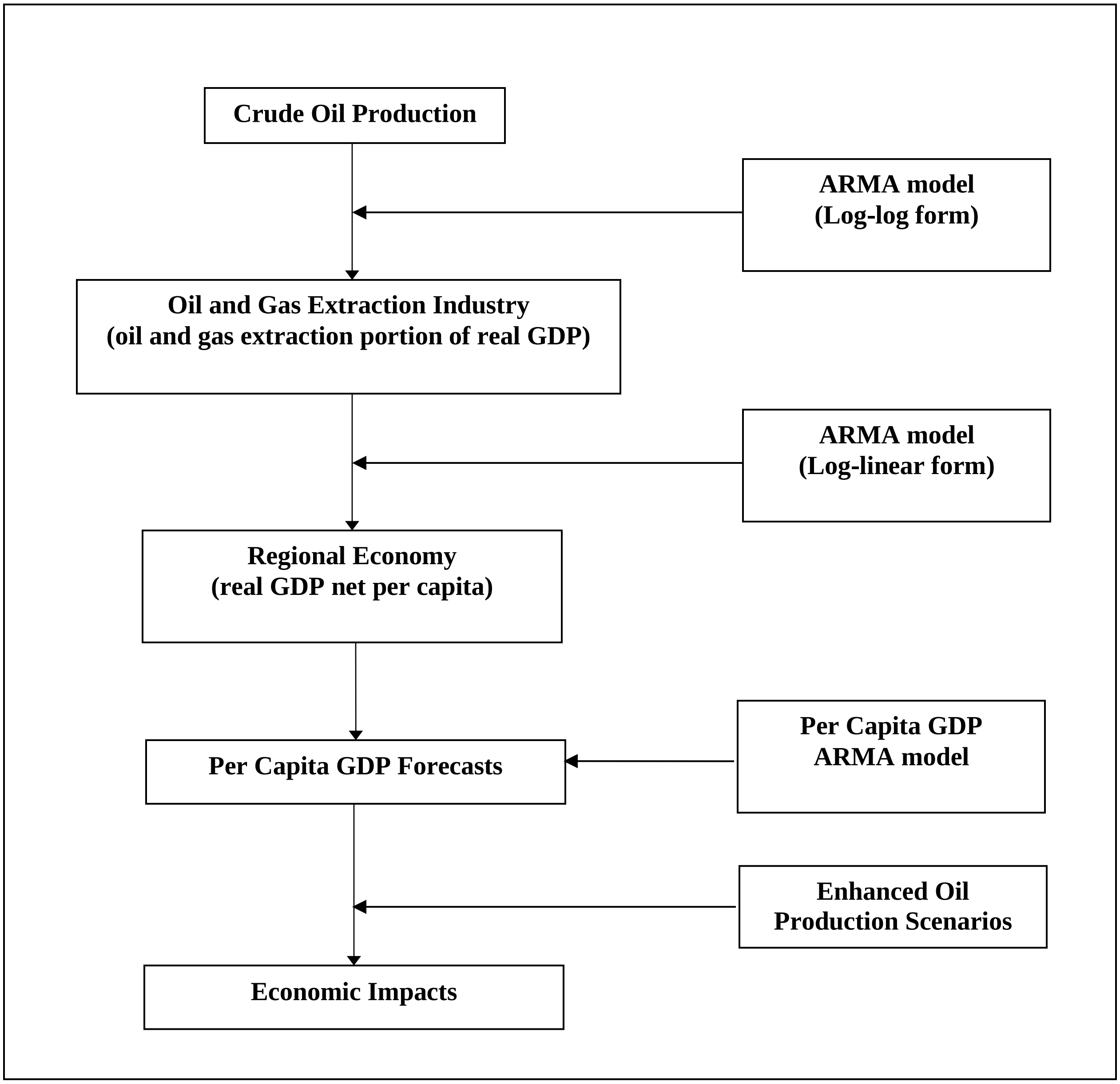
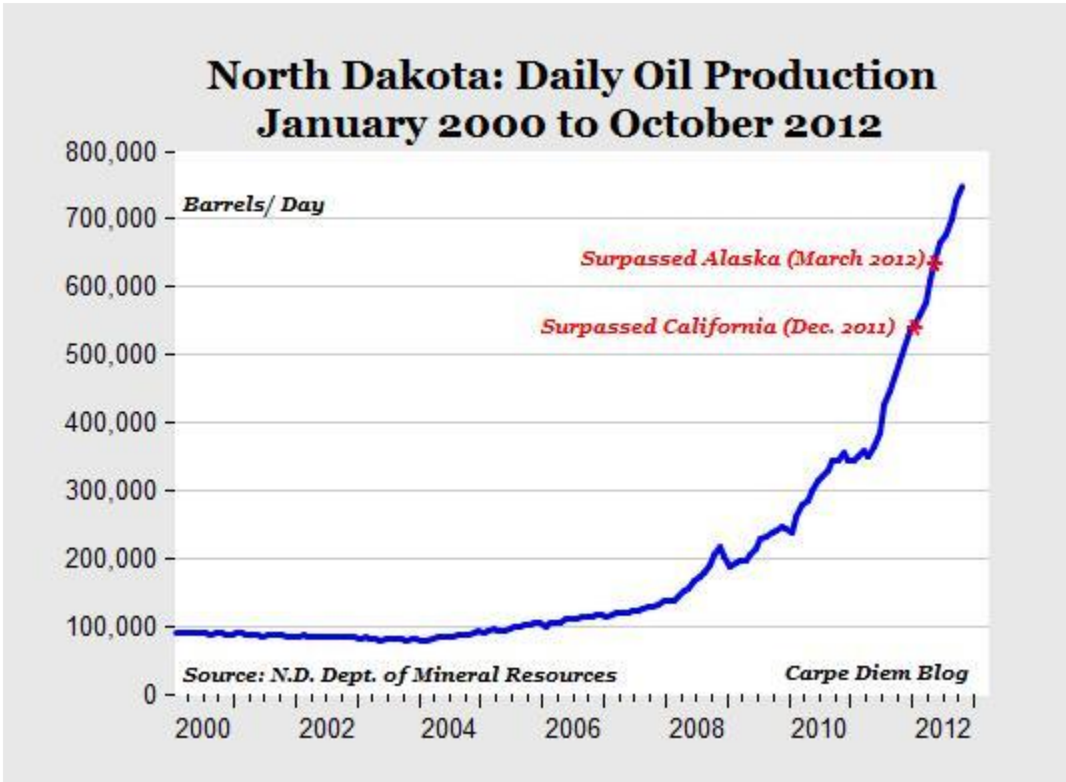


Figure 4. Recent North Dakota daily oil production pattern



Source: North Dakota Department of Minerals, cited in AEI Ideas, online edition, located at: http://www.aei-ideas.org/wp-content/uploads/2012/12/ndoil.jpg.

Table 4.1. Monthly unemployment rates: The five lowest unemployment rate states in 2012

Rank	State	Rate
1	NORTH DAKOTA	3.2
2	NEBRASKA	3.7
3	SOUTH DAKOTA	4.4
4	IOWA	4.9
4	WYOMING	4.9

Source: U.S. Bureau of Labor Statistics, located at: http://www.bls.gov/web/laus/laumstrk.htm.
1. Unemployment rates refer to a percentage of the labor force on the basis of place of residence.
2. The estimated rates are preliminary and seasonally adjusted. The current month is December, 2012. The last modified date of the data is January 18, 2013.

Table 4.2. Real GDP by state, selected states, 2008-2011

	Millions of chained (2005) dollars				Percent change				
	2008	2009	2010	2011	2008	2009	2010	2011*	2011 Ranking
U.S.	13,016,791	12,527,057	12,918,931	13,108,674	-0.7	-3.8	3.1	1.5	-
North Dakota	28,624	29,209	31,833	34,262	8.4	2.0	9.0	7.6	1
South Dakota	34,302	34,097	34,175	34,443	4.5	-0.6	0.2	0.8	31
Wyoming	31,369	32,088	31,919	31,542	5.2	2.3	-0.5	-1.2	50
California	1,756,115	1,673,333	1,701,912	1,735,360	-0.4	-4.7	1.7	2.0	10

Source: U.S. Bureau of Economic Analysis (BEA).
Note: *Estimates.

We seek two types of estimated parameter sets: the first set includes the effects of crude oil production on the oil/gas industry component of state GDP (*Oil and Gas GDP ARMA model*); the second set includes the effects on real (chained 2005 dollars) per capita state GDP in year *t* from an increase in state drilling activity in year *t-n* which is defined by the oil/gas extraction industry component of California GDP (*net GDP per capita ARMA model*). For the former model, we applied log-log ARMA models. For the latter, log-linear (semi-log) models were estimated.[5] Together, the two models enable us to link California oil production with California per capita GDP. Details describing our data and models are in Appendix A.

Background

Currently, oil and gas account for 63 percent of U.S. energy supply. They represent more than $1 trillion of the U.S.GDP, accounting for about 7.5 percent of the GDP. The oil and natural gas industry also supported about 9.2 million jobs in the domestic labor market in 2010 (Ryan, 2010).

Some economists have noted cases where the overall impacts of energy development on the economy are limited or even negative in the long run. These arguments, based on the broadly defined "Dutch Disease" literature, elaborate the idea that incentive and distributional effects, and other costs associated with energy development negatively affect other sectors, as well as currency appreciation at the national level (Weinstein and Partridge, 2011). Recent research (Papyrakis and Gerlagh, 2007; Kilkenny and Partridge, 2009; James and Aadland, 2011) considers Dutch Disease, the idea that a high degree of reliance on natural resource development can occur at the cost of other sectors' performance and can explain poor overall economic outcomes.

[5] The U.S. data are for the years 1981 to 2010. There are states where per capita GDP increases while oil production falls, but this is not the case for the oil boom states. We selected the semi-log model to effectively transfer the predicted net (of oil and gas) per capita GDP to total per capita GDP, maintaining the elasticity concept consistently through the two-stage models.

However, the relevance of Dutch Disease concerns in the complex, spatially integrated and diversified U.S. economy is questionable, as is its applicability to the California economy, which itself is the sixth largest in the world. Various recent studies elaborate the positive side. For example, PricewaterhouseCoopers LLP (2011) quantified the contributions of the U.S. oil and natural gas industry to the U.S. national and state economies in terms of employment, labor income (including wages and salaries and benefits, as well as proprietors' income), and value added using the 2009 IMPLAN input-output (I-O) model. The report estimated that the total employment impact of the industry on the national economy amounted to 9.2 million full-time and part-time jobs (5.3 percent of the total employment in the country) in 2009. The associated labor income was estimated to reach $534 billion (6 percent of the 2009 national labor income) and the industry's total value-added was $1.1 trillion (7.7 percent of the 2009 U.S. GDP).

Several other studies also utilized IMPLAN I-O models. Peach et al. (2009) estimated the economic impact of oil and gas extraction industries in New Mexico for 2008. The oil and gas sector employed more than 41,000 people in 2008 (5.1 percent of New Mexico's total private sector employment) and provided a total output of more than $19 billion directly. Furthermore, the industry contributed significant revenues to the state general fund in FY 2008, including federal minerals leasing ($564 million), oil and gas school tax revenues ($558 million), and state land office royalties ($460 million). Similarly, the Pennsylvania Economy League of Southwestern Pennsylvania, LLC (2008) developed the Pennsylvania oil and gas industry impact model of the state economy. The oil and gas industry in Pennsylvania provided a total economic impact of over $7 billion, more than 26,500 full and part-time jobs. The industry generated nearly $1 billion in employee compensation, $842 million in proprietors' income, and $1.9 billion in investor and property owner income. To estimate the economic and fiscal impacts of Colorado's oil and gas industry in 2010, Wobbekind et al. (2011) compared the oil and gas industry with other industries in the state, using an IMPLAN I-O model. The oil and gas industry contributed $31.9 billion to Colorado's economy in 2010 through direct and indirectly linked activities. Total employment, wages, and value added were estimated at 107,566 jobs, $6.6 billion, and $14.4 million, respectively.

Finally, Scott (2011) estimated the economic impacts of the extraction, refining, and pipeline industries for Louisiana in 2009. He applied the input-output multipliers available from the Bureau of Economic Analysis (BEA) of the U.S. Department of Commerce. Through both direct and multiplier effects, the three industries provided $77.3 billion in sales for Louisiana firms, generated over $16.1 billion in labor income, and supported 310,217 jobs in the state in 2009. Table 5 summarizes the various recent economic impact studies of the oil and gas industry.

Some previous industry-funded studies on the economic impacts of oil and natural gas industry generally overestimated the economic impacts because of the fixed coefficients assumption of the I-O approach. Unlike these studies, Barth (2010) applied conservative assumptions to estimate the economic impacts of natural gas development. Weinstein and Partridge (2011) accounted for the many and various costs and benefits of natural gas development in Ohio using a statistical analysis approach and concluded that an impact study can overestimate without properly considering these factors.

Table 5. Summary of oil and gas economic impact studies

Studies	Output ($billions)				Employment (1000s)				Labor Income ($ billions)				Value Added ($ billions)			
	DR	ID	IND	TO	DR	ID	IND	TO	DR	ID	IND	TO	DR	ID	IND	TO
PricewaterhouseCoopers LLP (2009); USA	-	-	-	-	-	-	-	9,161	-	-	-	534	-	-	-	1,082
Peach et al. (2009); NM	19.1	2.1	1.2	22.4	15.9	14.2	11.6	41.7	1.2	0.7	0.4	2.3	10.3	1.0	0.7	11.9
Pennsylvania Economy League of Southwestern Pennsylvania, LLC (2008); PA	4.5	1.2	1.3	7.1	10.5	5.3	10.8	26.6	1.1	0.3	0.4	1.8	-	-	-	-
Wobbekind et al. (2011); CO	21.5	5.9	4.5	31.9	43.8	29.2	34.5	107.6	3.2	1.9	1.5	6.6	8.1	3.6	2.8	14.4
Scott (2011); LA	-	-	-	77.3	-	-	-	310.2	-	-	-	16.1	-	-	-	-

Notes: 1. DR = Direct Impact.
2. ID = Indirect Impact.
3. IND = Induced Impact.
4. TO = Total Impact.

Time-Series Estimations

Log-linear net GDP per capita ARMA model

Based on the data sets prepared, the basic time-series model estimated in this analysis is the *autoregressive moving-average* (ARMA) model. As described in Appendix A, ARMA is an approach that best exploits information contained in time series trend data. As Bart (2010) and Weinstein and Partridge (2011) indicated, applying simulation-based approaches like I-O and CGE to longer term analyses can be especially risky because a very large number of parameters or relationships that must be expected to be stable for many years. The coefficients estimated from the ARMA approach reflect the recent trend in each state, while these economic models only use selected base-year coefficients. Therefore, statistics-based approaches make the best use of available data, and we used only the estimated parameters for this modeling work to be straightforward, even though probabilistic parameters using a bootstrapping method could have been applied to generate a variety of simulations.

Table 6 below shows semi-log (log-linear) coefficients for three states experiencing an oil drilling boom (North Dakota, Wyoming, and South Dakota) as well as California from data applied to the *net GDP per capita ARMA model*. Detailed information on the estimated parameters is shown in Appendix B for each state. Using an interaction coefficient term, impact parameters were calculated for each state. For example, the estimated coefficient of oil/gas industry GDP to net GDP per capita for California, 2.59, is the sum of -1.91 (LN_OG_{CA}) and 4.50 (INT_CA). Similarly, the estimated impact coefficients for the other three states are also shown. Among the three states, Wyoming has the highest semi-log coefficient (8.945) while South Dakota the lowest (2.591). North Dakota’s coefficient (5.198) is about half-way in between.

Table 6. Semi-log (log-linear) estimated coefficients, California, North Dakota Wyoming and South Dakota

State	Semi-log (Log-linear) Coefficients
CA	2.594
ND	5.198
WY	8.945
SD	2.951

Notes: 1. (Δ $1000 for net per capita GDP) / (% change oil and gas GDP). For example, the figure 2.594 indicates a one percent increase in oil/gas activity in California leads to a $2,594 change in net per capita GDP.
2. Coefficients represent recent (2002 and after) pattern of oil/gas portion of GDP associated with net GDP per capita.

Monterey Shale hydraulic fracturing scenario: Log-log oil and gas GDP ARMA model

In recent years, oil and gas production in various states has involved rapid growth from the adoption of new hydraulic fracturing ("fracking") technologies. North Dakota, Wyoming and South Dakota are recent stand-outs. If California's oil production were to follow the path of any of these boom states, the effects could be as significant. This is important because it would mean a reversal of recently expected trends which had included a decline in California oil production. If California were to experience a shale boom, this would not be a marginal change. This is why the recent experience of the oil boom states can be a useful guide. We used our model results to simulate California's oil production *if it were to follow the paths of the three other states' oil production boom* (see attached trends shown in Appendix D below).

Table 7 shows the estimated log-log coefficients of the crude oil production variable for California, as well as the three oil boom states estimated using the *oil and gas GDP ARMA model*. The detailed econometric model results estimated with the net GDP per capita ARMA model are shown in Appendix C, indicating the elasticity of state-level net GDP per capita (GDP net of oil and gas) with respect to crude oil production. Using an interaction coefficient term, the coefficient parameter was calculated for the three oil boom states. The estimated coefficient is 1.309 for North Dakota, which is the sum of 3.42 (LN_CO_{ND}) and -2.11 ($INT03\_CO_{ND}$). Similarly, Wyoming and South Dakota were estimated to be 1.167 and 3.295, respectively. In this log-log model, South Dakota has the highest elasticity, while Wyoming has the lowest. The parameter for California was estimated at -3.02.

Table 7. Log-log coefficients, crude oil production for California and three oil boom states

State	Log-log Coefficients for Oil Production
CA	-3.020
ND	1.309
WY	1.167
SD	3.295

Notes: 1. (% GAS/OIL GDP) / (% crude oil production). For example, the figure 1.309 indicates a one percent increase in crude oil production in North Dakota leads to a 1.309 percent change in oil/gas industry GDP.
2. Coefficients represent recent (2002 and after) patterns of oil production associated with oil/gas portion of state GDP.

Baseline Forecasts

We collected California data required for scenario development. Table 8 presents the ratios of two variables of interest (employment and personal income) to per capita GDP for California. Based on the latest ten-year (2001-2010) information collected from BEA, average, highest, lowest and year 2010 ratios were calculated. To examine impacts for California state and local taxes, we also collected detailed 2010 tax information from the State & Local Finance Data Query System and calculated taxes collected per dollar of total personal income. These are shown in Table 9. Detailed tax collection scenarios were developed by applying personal income ratios in Table 8 in each forecast year.

Table 8. California ratios: variables of interest (Employment and Personal income) to dollars of per capita GDP

10-year experience	Employment	Personal income
Average	435	30.19
Highest	505	31.11
Lowest	392	29.44
2010	392	31.11

Notes: 1. Ratios were calculated using California per capita GDP (based on the current $ GDP) for employment (unit: number of jobs) and personal income (unit: $ million) as in Chapter 4 outlined in this report.
2. The data are from the ten-year (2001-2010) California data from the Bureau of Economic Analysis (BEA). In 2010, the current per capita GDP for California was $50,285.

Table 9. California state and local taxes collected and per dollar of total personal income, 2010

Taxes	Amount (Units: $M)	Per $ of personal income
Property	$ 53,876.296	0.0344
Sales and gross receipts	$ 51,921.223	0.0332
Individual income	$ 45,646.436	0.0292
Corporate income	$ 9,114.589	0.0058
Motor vehicle license	$ 3,147.859	0.0020
Other taxes	$ 8,923.313	0.0057
Total Taxes	$ 172,629.716	0.1104
Total Personal Income	$ 1,564,209.000	

Source: Authors calculated taxes per dollar of total personal income based on State & Local Finance Data Query System. Source data taken from Tax Policy Center (http://slfdqs.taxpolicycenter.org/pages.cfm) (see Appendix F).

Scenario-based results: The economic impact on California

To estimate the economic impacts of future enhanced crude oil production in California, we applied percent changes of the California oil production forecast from 2015 to 2030 using the ratios of the key variables: employment, personal income, and tax collections to predicted per capita GDP values. As suggested in Tables 11.1 and 11.2, the economic forecasts of per capita GDP and the base year variable ratios are the baseline figures associated with the scenarios of percent change over baseline in Table 8. The high and low enhanced-drilling scenarios of Table 10 were used to produce the economic impacts with respect to three key variables (jobs, personal income, and tax collections) via the entire time-series model framework as suggested in Figure 3. The economic impacts in this section are, therefore, compared to the economic baselines in Table 11.1 and 11.2.

Table 10. California oil production forecasts: Percent change over baseline, low and high enhanced drilling cases

Percent change over baseline	**2015**	**2020**	**2025**	**2030**
Low enhanced drilling	6.2%	38%	36%	32%
High enhanced drilling	26%	139%	131%	79%

Note: California oil production forecast information from 2015 to 2030 in Appendix G.

Table 11.1. Baseline economic forecasts: California, 2015 to 2030 (no enhanced oil drilling)

Baseline economic forecasts	**2015**	**2020**	**2025**	**2030**
Predicted Per Capita GDP ($)	62,000	72,000	82,000	93,000
Employment	24,329,100	28,253,200	32,177,200	36,493,700
Personal income	1,928,600	2,239,700	2,550,700	2,892,900
Tax collections (details in Table 9.2)	212,900	247,300	281,600	319,400

Notes: 1) Per Capita GDPs were forecast using a time-series model described in Appendix E.
2) Values are rounded.
3) The base year of variable ratios applied are from 2010.

Units: 1) Employment: number of jobs.
2) Personal income and tax collections: $ millions.

Table 11.2. Detailed tax collections corresponding to baseline California oil production

Taxes	2015	2020	2025	2030
Property	66,300	77,000	87,700	99,500
Sales and gross receipts	64,000	74,400	84,700	96,000
Individual income	56,300	65,400	74,500	84,500
Corporate income	11,200	13,000	14,800	16,800
Motor vehicle license	3,900	4,500	5,100	5,800
Other taxes	11,000	12,800	14,500	16,500
Total Taxes	212,900	247,300	281,600	319,400

Notes: 1) Units: $ millions.
2) Values are rounded.

We applied both the oil/gas GDP elasticities of oil production estimated from the *log-log coefficient of crude oil production* for the three boom states and the net per capita GDP elasticities of oil/gas GDP from the *log-linear net GDP per capita ARMA model* of the three boom states. As already mentioned, of these North Dakota's were the most conservative – for the years that data for all key variables were available. The entire application framework is suggested in Figure 1, and the procedure to calculate the impacts is shown in Appendix H.

Tables 12.1.a and 12.1.b show results for the low enhanced drilling case. The median outcomes described in Table 3 are the median of these. The accompanying results, Tables 12.2.a. and 12.2.b, are also for the higher enhanced oil drilling case. We began with per capita GDP projections for the years 2015 through 2030 as in Table 11.1. Detailed tax impacts are in Tables 12.1.b and 12.2.b for the respective cases. Applying the North Dakota scenario, the oil production elasticities for the contributions to the California economy are decreasing from 0.1308 (0.8%/6.2%) in 2015 to 0.0872 (2.8%/32%) in 2030. Appendices I and J show that a similar pattern is found when applying elasticities for Wyoming and South Dakota.

Table 12.1.a. California Impacts: Changes from baseline, selected years, North Dakota scenario and low enhanced drilling case

Year	Jobs	Personal Income ($million)	Tax Collections ($million)	Percentage over baseline	Elasticity
2015	196,200	15,600	1,700	0.8%	0.1308
2020	1,206,700	95,700	10,600	4.3%	0.1127
2025	1,135,400	90,000	9,900	3.5%	0.0989
2030	1,026,800	81,400	9,000	2.8%	0.0872

Notes: 1) Per capita GDPs were forecast using time-series models described in Appendix E. The predicted per capita GDPs are in Table 11.1.
2) Values are rounded.

Table 12.1.b. California tax collection impact details

Taxes	2015	2020	2025	2030
Property	540	3,290	3,100	2,800
Sales and gross receipts	520	3,180	2,990	2,700
Individual income	450	2,790	2,630	2,380
Corporate income	90	550	520	470
Motor vehicle license	30	190	180	160
Other taxes	90	550	510	460
Total Taxes	1,700	10,600	9,900	9,000

Notes: 1) Units: $millions.
2) Values are rounded.

Table 12.2.a. California Impacts: Changes from baseline, selected years, North Dakota scenario and high enhanced drilling case

Year	Jobs	Personal Income ($million)	Tax Collections ($million)	Percentage over baseline	Elasticity
2015	827,700	65,600	7,200	4.2%	0.1308
2020	4,425,000	350,800	38,700	22.4%	0.1127
2025	4,170,300	330,600	36,500	21.1%	0.0989
2030	2,514,900	199,400	22,000	12.7%	0.0872

Notes: 1) Per capita GDPs were forecast using time-series models described in Appendix E. The predicted per capita GDPs are in Table 11.1.
2) Values are rounded.

Table 12.2.b. California tax collection impact details

Taxes	2015	2020	2025	2030
Property	2,260	12,070	11,370	6,860
Sales and gross receipts	2,180	11,650	10,980	6,620
Individual income	1,920	10,240	9,650	5,820
Corporate income	380	2,030	1,920	1,160
Motor vehicle license	130	700	660	400
Other taxes	370	2,000	1,880	1,140
Total Taxes	7,200	38,700	36,500	22,000

Notes: 1) Units: $ millions.
2) Values are rounded.

Summary and Conclusions

We prefer to emphasize our median forecasts (Table 3). We expect that a shale oil boom in California could yield between 512,000 and 2,815,800 new jobs statewide. As for any such boom, many of the new jobs will be filled by properly skilled job-seekers and their families moving into the state.

There are other important economic effects as well. For instance, in the median case, depending upon the year:

- State per-capita gross domestic product (GDP) grows by $1,600 to $11,000, or by 2.6% to 14.3%.

- Personal income grows by $40.6 billion to $222.3 billion, or by 2.1% to 10.0%.

- State & local government revenues (tax collections) grow by $4.5 billion to $24.6 billion, or by 2.1% to 10.0%.

Clearly, all forecasting exercises involve caveats. They are all made with the *assumption of other things equal*. We have tried to spell out the many assumptions used in this study. We also have shown various development scenarios, of which the North Dakota path (responding to assumed California enhanced oil-drilling scenarios) is the most conservative. The years for which we have all the data needed for this analysis correspond to North Dakota's experience *before* the most recent years—in which that activity has ramped up considerably. But unlike North Dakota, California is home to many more possible spin-off industry beneficiaries. Prominent among these are California's ports, which are poised to benefit from the full effects of oil boom scenarios in California and elsewhere in the U.S.

We used reduced-form models that do not explicitly report the complex inter-sectoral or inter-state relationships that give rise to the many outcomes. We expect to extend our current approach via the development of a more structured multi-level model that includes, for example, additional variables and more states to explain state per capita GDP. However, there are even much more sophisticated modeling approaches that could be applied. As always, the trade-offs involved in moving to any of these are complex.

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Appendices

Appendix A. Data and Models

The data used are from the Bureau of Economic Analysis (BEA) and the Bureau of Labor Statistics (BLS). The latter was used to build a real (constant dollar) GDP series. The data sets include:

- Bureau of Economic Analysis (1963 - 2010)
  - At the state level, these are selected for California and three oil boom states:
  - Gross domestic product (GDP): Total (all NAICS 2-digit sectors) + Oil/Gas Extraction
  - State populations
- Bureau of Labor Statistics (1963 - 2010)
  - Consumer Price Index (CPI): all urban consumers

Based on the data sets prepared, the basic time-series model estimated in this analysis is the *autoregressive moving-average* (ARMA) model. The ARMA (p, q) model with pth-order autoregressive term and qth-order moving-average terms specified is widely used for the analysis of time series data. It is an approach that best exploits information contained in a time series of trend data. Because ARMA model is an atheoretic approach, the best values for p and q will be selected when stationarity satisfies, several model statistics such as Akaike information criterion suggested in Appendices B and C are smallest, and the estimated coefficients for the key variables are significant.

To forecast macroeconomic variables such as GDP, inflation, unemployment rates, and many other economic variables, a popular method of forecasting is via the autoregressive moving average (ARMA) procedure, popularly known as the Box-Jenkins methodology. The ARMA procedure analyzes and forecasts equally spaced univariate time series data, transfer function data, and intervention data and provides a parsimonious description of a stationary or weakly stationary stochastic-process in terms of auto-regression and moving average. The emphasis of the ARMA procedure is not on constructing single-equation or simultaneous-equation models but rather on analyzing the probabilistic, or stochastic, properties of economic time series on their own (Gujarati and Porter, 2009).

The notation of the ARMA (p, q) procedure refers to a model with p autoregressive terms and q moving average terms and can be represented as:

$$y_t = \alpha + \beta_1 y_{t-1} + \beta_2 y_{t-2} + \cdots + \beta_p y_{t-p} + \varepsilon_t + \delta_1 \varepsilon_{t-1} + \delta_2 \varepsilon_{t-2} + \cdots + \delta_q \varepsilon_{t-q} \qquad (1)$$

where the intercept α is related to the mean of y_t, and the error terms ε_t are assumed to be uncorrelated random variables with $E[\varepsilon_t] = 0$ and $var(\varepsilon_t) = \sigma_\varepsilon^2$ (Griffiths et al., 1993).

Log-linear net GDP per capita ARMA model

We estimated net GDP per capita ARMA models for California and three oil boom states with log-linear form in equations (2).

- California: ARMA (1, 3)

$$GDP\_NPC_{CA,t} = \alpha + \beta LN\_OG_{CA,t} + \gamma GDP\_NPC_{CA,t-1} + \varepsilon_t + \sum_{i=1}^{3} \delta_i \varepsilon_{t-i} + \zeta\, d\_97_t + \eta\, d\_02_t + \theta\, INT_{CA,t} \qquad (2.1)$$

- North Dakota: ARMA (1, 0)

$$GDP\_NPC_{ND,t} = \alpha + \beta LN\_OG_{ND,t} + \gamma GDP\_NPC_{ND,t-1} + \varepsilon_t + \zeta\, d\_97_t + \eta\, d\_02_t + \theta\, INT_{ND,t} \quad (2.2)$$

- South Dakota: ARMA (3, 0)

$$GDP\_NPC_{SD,t} = \alpha + \beta LN\_OG_{SD,t} + \sum_{i=1}^{3} \gamma_i GDP\_NPC_{SD,t-i} + \varepsilon_t + \zeta\, d\_97_t + \eta\, d\_02_t + \theta\, INT_{SD,t} \quad (2.3)$$

- Wyoming: ARMA (3, 3)

$$GDP\_NPC_{WY,t} = \alpha + \beta LN\_OG_{WY,t} + \sum_{i=1}^{3} \gamma_i GDP\_NPC_{WY,t-i} + \varepsilon_t + \sum_{j=1}^{3} \delta_j\, \varepsilon_{t-j} + \zeta\, d\_97_t + \eta\, d\_02_t + \theta\, INT_{WY,t} \quad (2.4)$$

where, GDP_NPC_s = Net per capita real state GDP, defined as [(real GDP of all industries total – real GDP of the oil and gas extraction industry)/population] for a state s; this is state GDP net of the oil and gas contribution to state GDP;

LN_OG_s = ln(real state GDP of from oil and gas extraction) for a state s (California, North Dakota, Wyoming, and South Dakota);

t = time period (1981~2010);

γ = AR term coefficient;

δ = MA term coefficient;

ζ and η = period dummy coefficients;

θ = interaction term coefficient;

ln = natural log;

d_97_t = dummy variable that represents industrial classification system change of the U.S. in 1997, given to 1 if t is greater or equal to 1997, and 0 otherwise;

d_02_t = a year dummy with d_02=1, if t is greater or equal to 2002; and 0, otherwise, when per capita GDP showed the most dominant change.

$INT_{s,t}$ = interaction term that was calculated from multiplication of d_02 and LN_OG_s; it stands for slope drifter.

Log-log oil and gas GDP ARMA model

The ARMA models for oil-gas GDP and crude oil production for California and the oil boom states are presented in equations (3):

- California: ARMA (2, 1)

$$LN\_OG_{CA,t} = \alpha + \beta LN\_CO_{CA,t} + \sum_{i=1}^{2} \gamma_i LN\_OG_{CA,t-i} + \varepsilon_t + \delta\, \varepsilon_{t-1} + \zeta d\_97_t + \sum_{j=4}^{6} \eta_j d\_rec_{jt} \quad (3.1)$$

- North Dakota: ARMA (2, 1)

$$LN\_OG_{ND,t} = \alpha + \beta LN\_CO_{ND,t} + \sum_{i=1}^{2} \gamma_i LN\_OG_{ND,t-i} + \varepsilon_t + \delta\, \varepsilon_{t-1} + \lambda d\_03_t + \zeta d\_97_t + \vartheta INT03\_CO_{ND,t} + \sum_{j=3}^{4} \eta_j d\_rec_{jt} \quad (3.2)$$

- South Dakota: ARMA (3, 2)

$$LN\_OG_{SD,t} = \alpha + \beta LN\_CO_{SD,t} + \sum_{i=1}^{3} \gamma_i LN\_OG_{SD,t-i} + \varepsilon_t + \sum_{j=1}^{2} \delta_j \varepsilon_{t-j} + \zeta d\_97_t + \sum_{j=3}^{6} \eta_j d\_rec_{nt} \quad (3.3)$$

- Wyoming: ARMA (2, 3)

$$LN\_OG_{WY,t} = \alpha + \beta LN\_CO_{WY,t} + \sum_{i=1}^{2} \gamma_i LN\_OG_{WY,t-i} + \varepsilon_t + \sum_{j=1}^{3} \delta_j \varepsilon_{t-j} + \zeta d\_97_t + \sum_{j=4}^{5} \eta_j d\_rec_{jt} \quad (3.4)$$

where, LN_OG_s = ln(real state GDP of from oil and gas extraction) for a state s;
LN_CO_s = ln(crude oil production) for a state s (California, North Dakota, Wyoming, and South Dakota);
t = time period (1981~2010);
γ = AR term coefficient;
δ = MA term coefficient;
ζ, λ, and η = period dummy coefficients;
ϑ = interaction term coefficient;
ln = natural log;
d_97_t = a dummy variable that represents industrial classification system change for the U.S. in 1997, set to 1 if t is greater or equal to 1997, and 0 otherwise;
d_03_t = a year dummy with d_03=1, if t is greater or equal to 2003, and 0 otherwise when the ND's oil-gas GDPs had a sizable change;
$INT03\_CO_{s,t}$ = interaction term that was calculated from multiplication of d_03 and LN_CO_s; it stands for slope drifter;
d_rec_{jt} = a recession period dummy with d_rec_{jt}=1, if t is in recession periods, and 0 otherwise (Hall, 2007); the following dummy refers to:
d_rec_{3t}=1 if t=1979, 1980, 1981, and 1982, and 0 otherwise;
d_rec_{4t}=1 if t=1990, 1991, and 1992, and 0 otherwise;
d_rec_{5t}=1 if t=2001, 2002, and 2003, and 0 otherwise; and
d_rec_{6t}=1 if t=2008, and 2009, and 0 otherwise.

Appendix B. Log-Linear net GDP per capita ARMA model Estimations

Table B1. California

Variable	Coefficient		Std. Error	t-Statistic	Prob.
Intercept	54.2737	***	6.8394	7.9355	0
LN_OG_{CA}	-1.9126	**	0.8122	-2.3548	0.0283
INT_CA	4.5068	***	0.7062	6.3816	0
D_97	2.6221	***	0.7896	3.3208	0.0032
D_02	-34.8120	***	5.7391	-6.0658	0
AR(1)	0.5497	**	0.2058	2. 6705	0.0143
MA(1)	0.6452	***	0.1290	5.0033	0.0001
MA(2)	-0.6113	***	0.1218	-5.0186	0.0001
MA(3)	-0.9868	***	0.1385	-7.1237	0
R-squared	0.977		Akaike info criterion		2.8050
Adjusted R-squared	0.969		Schwarz criterion		3.2254
Log likelihood	-33.0756		Durbin-Watson stat		2.0503
F-statistic	113.8605	***			

Note: *** p<0.01, ** p<0.05, and * p<0.1.

Table B2. North Dakota

Variable	Coefficient		Std. Error	t-Statistic	Prob.
Intercept	35.9207	***	4.3630	8.2331	0
LN_OG_{ND}	-1.3746	**	0.6228	-2.2071	0.0371
INT_ND	6.5721	***	1.1233	5.8509	0
D_97	1.2784		1.8706	0.6834	0.5009
D_02	-25.4404	***	5.6910	-4.4703	0.0002
AR(1)	0.3998	*	0.2327	1. 7186	0.0986
R-squared	0.964		Akaike info criterion		3.6728
Adjusted R-squared	0.956		Schwarz criterion		3.9350
Log likelihood	-49.0920		Durbin-Watson stat		1.9695
F-statistic	127.4281	***			

Note: *** p<0.01, ** p<0.05, and * p<0.1.

Table B3. Wyoming

Variable	Coefficient		Std. Error	t-Statistic	Prob.
Intercept	49.2226	***	8.1516	6.0384	0
LN_OG_WY	-2.1879	**	0.9792	-2.2344	0.0377
INT_WY	11.1332	***	1.1612	9.5874	0
D_97	2.0103		1.4781	1.3601	0.1897
D_02	-79.4015	***	9.0533	-8.7704	0
AR(1)	0.5957	**	0.2177	2.7365	0.0131
AR(2)	-0.01292		0.3078	-0.0420	0.967
AR(3)	-0.3822	*	0.2196	-1.7405	0.0979
MA(1)	-0.9382	***	0.0173	-54.1397	0
MA(2)	-0.9593	***	0.0257	-37.3762	0
MA(3)	0.9091	***	0.0219	41.5206	0
R-squared	0.985		Akaike info criterion		3.2121
Adjusted R-squared	0.977		Schwarz criterion		3.7259
Log likelihood	-37.1816		Durbin-Watson stat		2.0186
F-statistic	123.3047	***			

Note: *** p<0.01, ** p<0.05, and * p<0.1.

Table B4. South Dakota

Variable	Coefficient		Std. Error	t-Statistic	Prob.
Intercept	32.6142	***	0.9661	33.7570	0
LN_OG_SD	-2.1408	***	0.3336	-6.4166	0
INT02_SD	5.0923	**	2.2964	2.2175	0.0372
D_97	4.1038	***	1.0840	3.7857	0.001
D_02	-3.8762		6.5287	-0.5937	0.5588
AR(1)	0.2018		0.2009	1.0040	0.3263
AR(2)	-0.1582		0.2027	-0.7803	0.4435
AR(3)	-0.3760	*	0.1940	-1.9385	0.0655
R-squared	0.946		Akaike info criterion		4.2183
Adjusted R-squared	0.929		Schwarz criterion		4.5919
Log likelihood	-55.2741		Durbin-Watson stat		2.1848
F-statistic	55.0875	***			

Note: *** p<0.01, ** p<0.05, and * p<0.1.

Appendix C. Log-Log oil and gas GDP ARMA model Estimations

Table C1. California

Variable	Coefficient		Std. Error	t-Statistic	Prob.
Intercept	46.4765	***	15.5091	2.9967	0.0069
LN_CO_{CA}	-3.0202	**	1.2681	-2.3817	0.0268
D_97	-0.1331		0.3237	-0.4112	0.6851
D_REC4	0.1448		0.1997	0.7250	0.4764
D_REC5	-0.2506		0.1974	-1.2694	0.2182
D_REC6	0.0463		0.1893	0.2445	0.8092
AR(1)	1.4426	***	0.1507	9.5747	0
AR(2)	-0.5258	***	0.1531	-3.4353	0.0025
MA(1)	-0.9997	***	0.1187	-8.4197	0
R-squared	0.8723		Akaike info criterion		0.0825
Adjusted R-squared	0.8236		Schwarz criterion		0.5029
Log likelihood	7.7621		Durbin-Watson stat		1.9579
F-statistic	17.9264	***			

Note: *** p<0.01, ** p<0.05, and * p<0.1.

Table C2. North Dakota

Variable	Coefficient		Std. Error	t-Statistic	Prob.
Intercept	-29.2946	***	3.0186	-9.7047	0
LN_CO_{ND}	3.4189	***	0.2866	11.9308	0
$INT03\_CO_{ND}$	-2.1099	***	0.2737	-7.7080	0
D_03	22.4627	***	2.8505	7.8803	0
D_97	-1.7743	***	0.0971	-18.2692	0
D_REC3	0.3579		0.4436	0.8067	0.4294
D_REC4	-0.1301		0.1456	-0.8937	0.3821
AR(1)	0.7084	***	0.2187	3.2398	0.0041
AR(2)	-0.2652		0.2051	-1.2933	0.2107
MA(1)	-1.0000	***	0.0000	-378344.6	0
R-squared	0.9852		Akaike info criterion		-0.3345
Adjusted R-squared	0.9785		Schwarz criterion		0.1326
Log likelihood	15.0169		Durbin-Watson stat		2.1331
F-statistic	147.9601	***			

Note: *** p<0.01, ** p<0.05, and * p<0.1.

Table C3. Wyoming

Variable	Coefficient		Std. Error	t-Statistic	Prob.
Intercept	-3.4536		4.85287	-0.71167	0.4853
LN_CO_WY	1.0192	**	0.4241	2.403136	0.0266
INT04_CO_WY	0.1476	***	0.018343	8.045608	0
D_97	-0.7753	***	0.162597	-4.768167	0.0001
D_REC4	0.0301		0.113077	0.266539	0.7927
D_REC5	0.6647	***	0.152025	4.372579	0.0003
AR(1)	0.5733	**	0.241697	2.372029	0.0284
AR(2)	-0.1186		0.227098	-0.522412	0.6074
MA(1)	-0.4670	***	0.102346	-4.563009	0.0002
MA(2)	-0.3885	**	0.138331	-2.808504	0.0112
MA(3)	0.9168		0.095518	9.598283	0
R-squared	0.941578		Akaike info criterion		-0.20602
Adjusted R-squared	0.91083		Schwarz criterion		0.307752
Log likelihood	14.09031		Durbin-Watson stat		2.345799
F-statistic	30.62219	***			

Note: *** p<0.01, ** p<0.05, and * p<0.1.

Table C4. South Dakota

Variable	Coefficient		Std. Error	t-Statistic	Prob.
Intercept	-19.9359	***	5.310459	-3.754082	0.0015
LN_CO_SD	3.2954	***	0.758939	4.342145	0.0004
D_97	-2.8964	***	0.327384	-8.847204	0
D_REC3	-0.6674	*	0.364062	-1.833285	0.0834
D_REC4	0.0471		0.142234	0.331445	0.7441
D_REC5	0.0811		0.235741	0.344025	0.7348
D_REC6	-0.0872		0.16678	-0.522828	0.6075
AR(1)	1.2237	***	0.260589	4.695948	0.0002
AR(2)	-0.0563		0.409927	-0.137261	0.8923
AR(3)	-0.2524		0.22355	-1.129198	0.2736
MA(1)	-0.0524		0.355542	-0.147294	0.8845
MA(2)	0.9999	***	0.137973	7.246896	0
R-squared	0.956547		Akaike info criterion		0.713803
Adjusted R-squared	0.929993		Schwarz criterion		1.274282
Log likelihood	1.292953		Durbin-Watson stat		2.099572
F-statistic	36.02196	***			

Note: *** p<0.01, ** p<0.05, and * p<0.1.

Appendix D. Historical Patterns of Crude Oil Production—Select U.S. States

Figure D1. Crude Oil Production: California and North Dakota

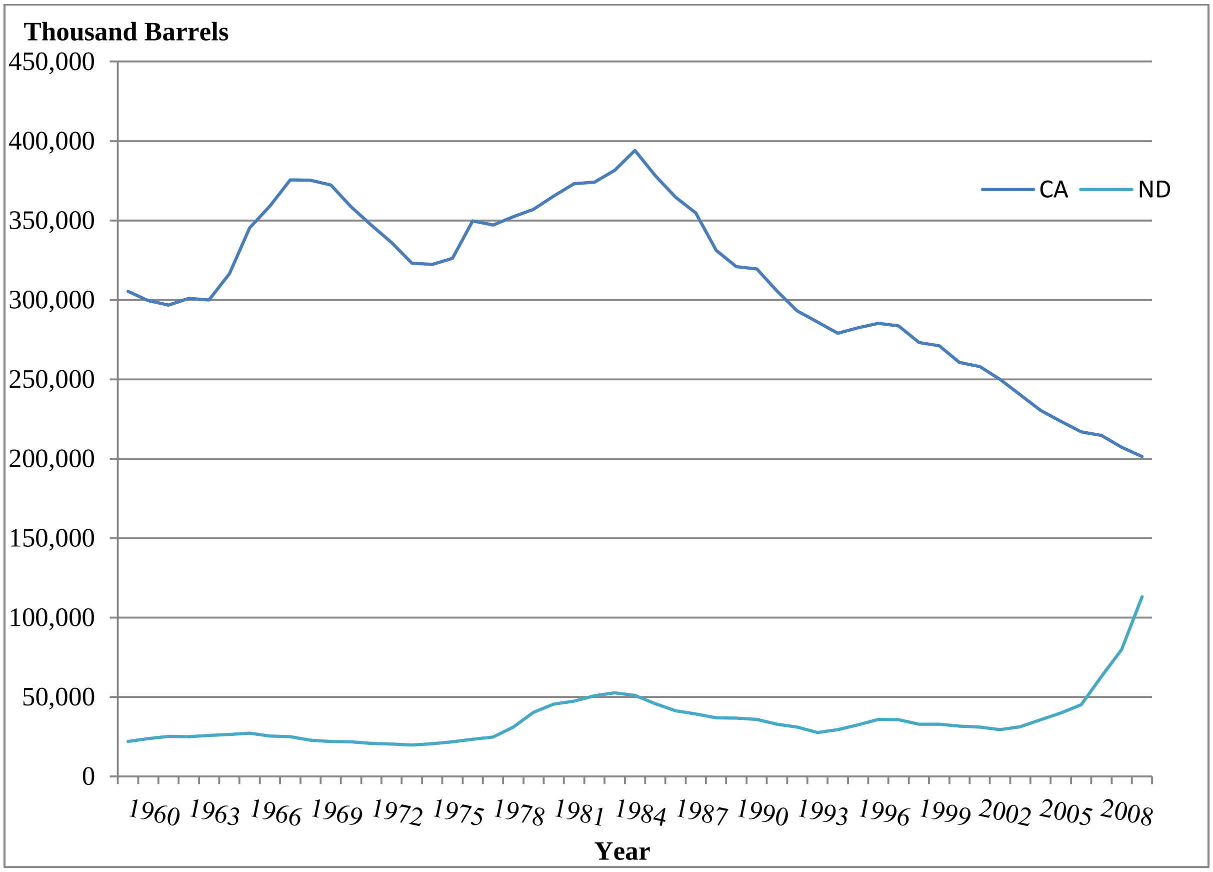


Figure D2. Recent crude oil production, Wyoming

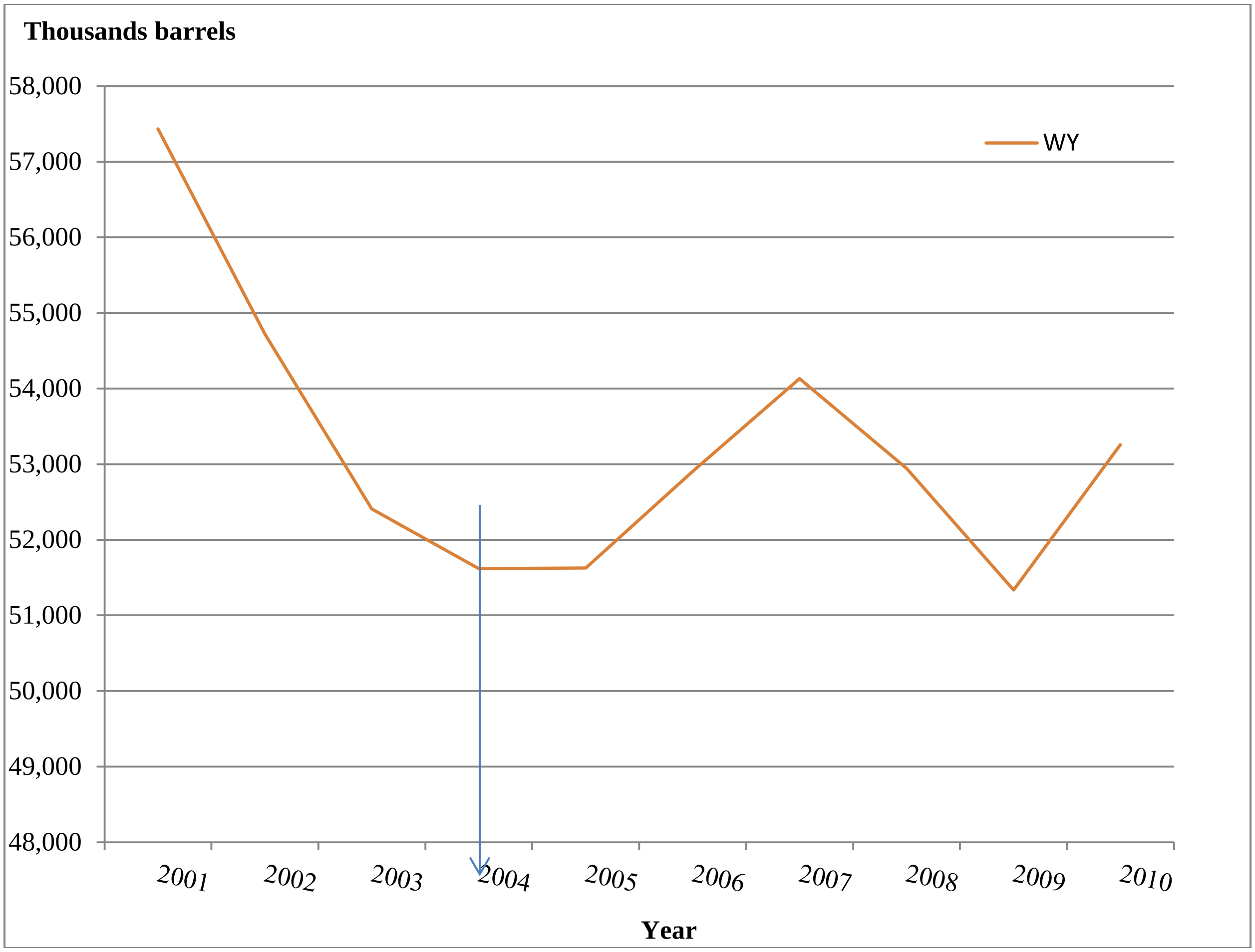
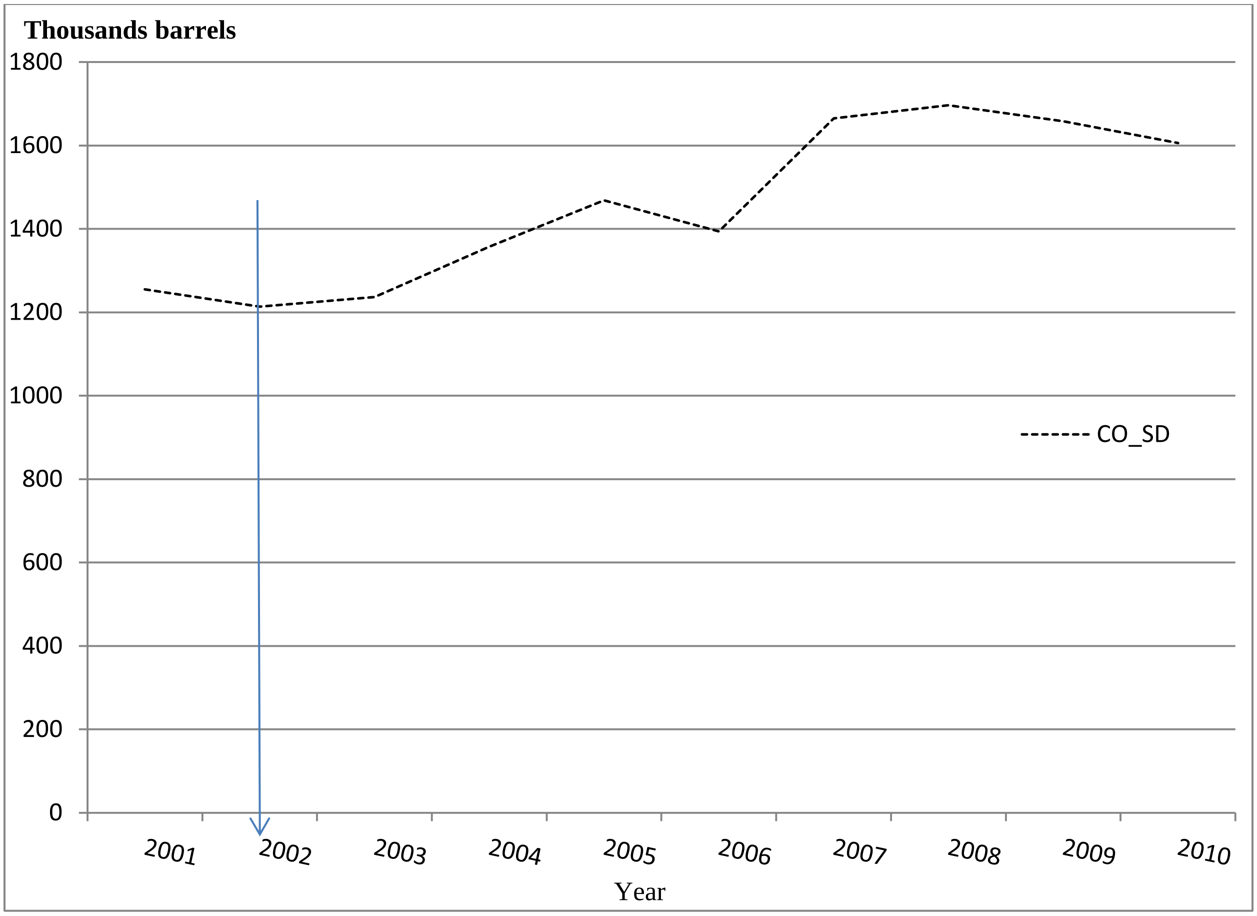


Figure D3. Recent crude oil production, South Dakota



Appendix E. Per Capita GDP Time-Series Model Specified for California

For forecast years 2015, 2020, 2025 and 2030.

- CA: ARMA (1, 1)

$$GDP\_PC_{CA,t} = \alpha + \beta GDP\_PC_{CA,t-1} + \varepsilon_t + \gamma\varepsilon_{t-1} + \delta d\_97_t + \sum_{i=1}^{6} \zeta_i d\_rec_{it} \text{ (D.1)}$$

where, GDP_PC_{CA} = (current GDP of all industries total/population) for California;

t = time period (1963~2010);

β = AR term coefficients;

γ = MA term coefficients;

d_97 = a dummy variable that represents industrial classification system change of the U.S. in 1997, given to 1 if t is greater or equal to 1997 and 0 otherwise;

d_rec_{it} = a recession period dummy with d_rec_{it}=1, if t is in the recession periods and 0, otherwise (Hall, 2007), and refer to:

d_rec_{1t}=1 if t=1970, 1971 and 0 otherwise;

d_rec_{2t}=1 if t=1974, 1975 and 0 otherwise;

d_rec_{3t}=1 if t=1979, 1980, 1981, 1982 and 0 otherwise;

d_rec_{4t}=1 if t=1990, 1991, 1992 and 0 otherwise;

d_rec_{5t}=1 if t=2001, 2002, 2003 and 0 otherwise; and

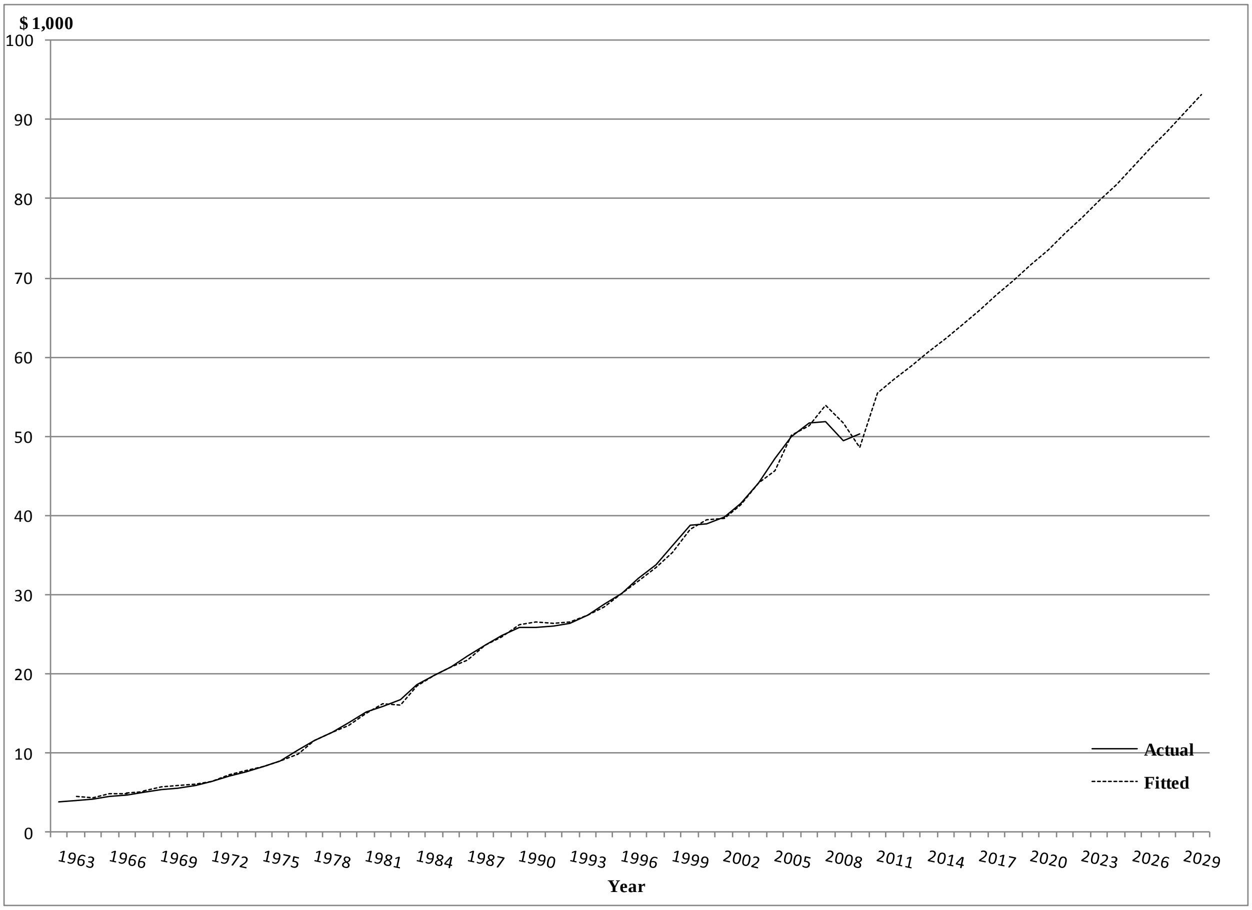
d_rec_{6t}=1 if t=2008, 2009 and 0 otherwise.

Table E1. Model results

Variable	Coefficient		Std. Error	t-Statistic	Prob.
Intercept	-29.7551		37.4223	-0.7951	0.4316
D_97	0.4546		0.4499	1.0107	0.3187
D_REC1	0.0543		0.5098	0.1066	0.9157
D_REC2	0.1297		0.5089	0.2548	0.8003
D_REC3	0.2915		0.3788	0.7695	0.4465
D_REC4	0.2672		0.1939	1.3776	0.1766
D_REC5	-1. 1292	***	0.2325	-4.8571	0.0000
D_REC6	0.3714		0.5690	0.6528	0.5179
AR(1)	1.0195	***	0.0134	76.3080	0.0000
MA(1)	0.9466	***	0.0348	27.2021	0.0000
R-squared	0.9983		Akaike info criterion		2.3244
Adjusted R-squared	0.9979		Schwarz criterion		2.7181
Log likelihood	-44.6242		Durbin-Watson stat		1.7672
F-statistic	2445.088	***			

Note: *** p<0.01, ** p<0.05, and * p<0.1.

Figure E1. Real per capita GDP forecast for California: No recession assumption



Appendix F. California State and Local Taxes Collected, 2010

Table F1. California State and Local Taxes Collected, 2010

Taxes	Amount	Proportions
Property	$ 53,876,296	0.3121
Sales and gross receipts	$ 51,921,223	0.3008
Individual income	$ 45,646,436	0.2644
Corporate income	$ 9,114,589	0.0528
Motor vehicle license	$ 3,147,859	0.0182
Other taxes	$ 8,923,313	0.0517
Total Taxes	$ 172,629,716	1.0000

Source: http://slfdqs.taxpolicycenter.org/pages.cfm.
Units: thousands.

Appendix G. California Projected Advanced-Technology Oil Production

Table G1. California projected advanced-technology oil production (millions barrels per day)

Scenario	2015	2020	2025	2030
EIA Reference Case (A)	0.23	0.21	0.21	0.20
Total Advanced-Technology Oil Production (B)	0.025	0.035	0.04	0.05
CA Total Crude Oil Production (C)	0.49	0.47	0.48	0.47
Lower-base Delta=[(A-B)/C]	0.26	0.38	0.36	0.32
Modified Lower-base Delta	0.06	0.38	0.36	0.32
Upper-base Delta	0.26	1.39	1.31	0.79

Note: EIA forecast California oil production includes both conventional and unconventional (advanced-technology) production. To isolate California conventional oil production used as the basis for our calculations, projected tight oil production for Monterey in "EIA Petroleum and Biofuels Outlook" was examined. Exponential growth rate was assumed to modify change for 2015. Monterey production is subtracted from the California total to derive California conventional production projections. High enhanced drilling was calculated based on "Decline Curve Analysis" method calculation in Chapter 3 of this report.

Appendix H. Step-by-Step Procedure for Scenario Analysis

Step-by-Step Procedure to Calculate Oil/Gas GDP Effect on California Economy

An oil/gas GDP effects test was implemented to illustrate the *log-linear net GDP per capita ARMA model* results. The estimated coefficient of GDP_OG_{CA} suggests the contribution of oil and gas drilling activity (measured in dollars) to the increase of California real GDP per capita portion that excludes oil and gas drilling activity. The following conditions are used:

1. Assumed California oil/gas GDP increase from baseline;
2. Base year 2010 current GDP and population (3.74M) of California; and
3. California's oil/gas elasticity applied in Table 6.

The steps are as follows:

- **Step 1.** Net Per Capita GDP increase = \$259.4 = \$1000x2.594x0.1; and 10% per capita GDP increase in Oil and Gas Industry = \$35.32 =\$1,319M/ 3.74M

- **Step 2.** Per Capita GDP increase = \$329.09 = {\$35.32 (10% per capita GDP increase in Oil and Gas Industry) + \$259.4 (Net Per Capita GDP increase)} x 1.12 (current dollar weight)

- **Step 3.** Increase in employment = 129,136 = \$329.09 x 392.41 (lowest employment ratio); and percentage increase in employment = 0.65% = 100 x (129,136 / 19,732,278)

- **Step 4.** Increase in total personal income = \$9,687M = \$329.09 x 29.43667 (lowest personal income ratio); and percentage increase in total personal income = 0.62% = 100 x (\$9,687M / \$1,564,209M)

To illustrate, if GDP_OG_{CA} were to increase by 10 percent in year t, the net real GDP per capita decreases by \$259 on average, if all other conditions are constant. Taking the proportion of total real GDP per capita to our reduced version, this means that California GDP per capita would grow by \$329 in 2010. All such projections are *ceteris paribus* (other things equal). Note that we are making no claims about associated long term structural changes in the California economy for this type of scenario analysis.

Calculating Crude Oil Production Impacts on California's economy, N. Dakota Pattern

We illustrate, applying the North Dakota pattern to estimate economic impacts for California with an assumed oil production change of 10 percent. Total employment would increase 1.6 percent; and total personal income 1.5 percent.

Conditions:

1. Assumed crude oil production in California increase from baseline by 10 percent (=20,138.5 thousand barrels).
2. Base year 2010 current GDP and population (3.74M) of California.
3. North Dakota's oil/gas coefficient (5.198) applied in Table 6.
4. North Dakota's oil production coefficient (1.309) applied in Table 7.

Procedure:

- **Step 1.** % Increase in Oil/Gas GDP = 13.1% = 10% x 1.309; and Per Capita GDP increase in Oil and Gas Industry = $46.24 = 13.1% x {$353.26M / 3.74M (population in 2010)}
- **Step 2.** Net GDP Per Capita increase = $ 680.35 = $1000 x 5.198 x 0.131
- **Step 3.** Per Capita GDP increase in current dollars= $ 811.26 = {$46.24 (Per Capita GDP increase in Oil and Gas Industry) + $680.35 (Net Per Capita GDP increase)} x 1.116 (current dollar weight)
- **Step 4.** Increase in employment = 318,342 = $811.26 x 392.41 (lowest employment ratio); and percentage increase in employment = 1.613% = 100 x (318,342 / 19,732,278)
- **Step 5.** Increase in total personal income = $23,881M = $811.26 x 29.437 (lowest personal income ratio); and percentage increase in total personal income = 1.527%= 100 x ($23,881M / $1,564,209M)

Based on ratios of key variables (employment, personal Income, and tax collections) to per capita GDP as suggested in Tables 8 and 9, scenarios that applied the various boom states' oil/gas GDP elasticities of oil production estimated from the *log-log coefficient of crude oil production for the boom states* were tested, combined with the estimated coefficients from the *log-linear net GDP per capita ARMA model*. The step-by-step procedure explains how to measure the oil-production impacts for North Dakota with assumed conditions with the lowest (most conservative) ratios. We assume that the oil production level of California increases 10 percent for an oil production increase in a near future. Also, we assume California oil increase pattern would be consistently similar to each boom state pattern. The summary of results with the 10 percent assumption and alternative trajectories for California is presented in Table H.1.

Table H1. Results summary assuming alternate economic trajectories for California

	North Dakota		Wyoming		South Dakota	
	Jobs	Personal Income ($M)	Jobs	Personal Income ($M)	Jobs	Personal Income ($M)
Average	351,700	24,500	525,200	36,600	527,185	36,713
Percentage	1.78%	1.57%	2.66%	2.34%	2.67%	2.35%
Lowest	318,300	23,900	475,300	35,700	477,100	35,800
Percentage	1.61%	1.53%	2.41%	2.28%	2.42%	2.29%
Highest	409,300	25,200	611,200	37,700	613,500	37,800
Percentage	2.07%	1.61%	3.10%	2.41%	3.11%	2.42%

Note: Values are rounded.

All such projections are *ceteris paribus* (other things equal) and there are no claims about associated structural changes in the California economy in Tables 9. Job elasticity of oil production change is in the range between 0.161 to 0.311. Similarly, the personal income elasticities are in the range between 0.153 and 0.242.

Appendix I. Other Scenario-Based Economic Impact Results: Wyoming

Other boom-state scenario-based economic impact results with crude oil production forecasts on California are presented for Wyoming for 2015 to 2030.

Table I1a. California impacts: Wyoming path and low enhanced drilling scenario

Year	Jobs	Personal Income ($M)	Tax Collections ($M)	Percentage over baseline	Elasticity
2015	293,000	23,200	1,800	1.2%	0.1954
2020	1,801,700	142,800	11,200	6.4%	0.1682
2025	1,695,300	134,400	10,600	5.3%	0.1477
2030	1,533,200	121,500	9,600	4.2%	0.1303

Notes: 1) Per capita GDPs were forecast using time-series models described in Appendix E. The predicted per capita GDPs are in Table 9.1.
2) Values are rounded.

Table I1b. California Tax Collection Impacts (Units: $M): Wyoming path and low enhanced drilling scenario

Taxes	2015	2020	2025	2030
Property	570	3,500	3,300	2,980
Sales and gross receipts	550	3,380	3,180	2,880
Individual income	480	2,970	2,800	2,530
Corporate income	100	590	560	500
Motor vehicle license	30	200	190	170
Other taxes	90	580	550	490
Total Taxes	1,800	11,200	10,600	9,600

Notes: 1) Units: $ millions.
2) Values are rounded.

Table I2a. California impacts: Wyoming path and high enhanced drilling scenario

Year	Jobs	Personal Income ($M)	Tax Collections ($M)	Percentage over baseline	Elasticity
2015	1,235,900	98,000	7,700	5.1%	0.1954
2020	6,607,100	523,800	41,200	23.4%	0.1682
2025	6,226,800	493,600	38,800	19.4%	0.1477
2030	3,755,100	297,700	23,400	10.3%	0.1303

Notes: 1) Per capita GDPs were forecast using time-series models described in Appendix E. The predicted per capita GDPs are in Table 9.1.
2) Values are rounded.

Table I2b. California tax collection impacts (Units: $M): Wyoming path and high enhanced drilling scenario

Taxes	2015	2020	2025	2030
Property	2,400	12,840	12,100	7,300
Sales and gross receipts	2,320	12,390	11,680	7,040
Individual income	2,040	10,900	10,270	6,200
Corporate income	400	2,170	2,040	1,230
Motor vehicle license	140	750	700	420
Other taxes	400	2,130	2,010	1,210
Total Taxes	7,700	41,200	38,800	23,400

Notes: 1) Units: $ millions.
2) Values are rounded.

Appendix J: Other Scenario-Based Economic Impact Results: South Dakota

Other boom-state scenario-based economic impact results with crude oil production forecasts for California are presented for South Dakota for 2015 to 2030.

Table J1a. California Impacts: South Dakota path and low enhanced drilling scenario

Year	Jobs	Personal Income ($M)	Tax Collections ($M)	Percentage over baseline	Elasticity
2015	294,100	23,300	1,800	1.2%	0.1961
2020	1,808,500	143,400	11,300	6.4%	0.1689
2025	1,701,800	134,900	10,600	5.3%	0.1483
2030	1,539,000	122,000	9,600	4.2%	0.1307

Notes: 1) Per capita GDPs were forecast using time-series models described in Appendix E. The predicted per capita GDPs are in Table 9.1.
2) Values are rounded.

Table J1b. California tax collection impacts (Units: $M): South Dakota path and low-enhanced drilling scenario

Taxes	2015	2020	2025	2030
Property	570	3,520	3,310	2,990
Sales and gross receipts	550	3,390	3,190	2,890
Individual income	490	2,980	2,810	2,540
Corporate income	100	590	560	500
Motor vehicle license	30	200	190	170
Other taxes	90	580	550	500
Total Taxes	1,800	11,300	10,600	9,600

Notes: 1) Units: $ millions.
2) Values are rounded.

Table J2a. California impacts: South Dakota path and high enhanced drilling scenario

Year	Jobs	Personal Income ($M)	Tax Collections ($M)	Percentage over baseline	Elasticity
2015	1,240,600	98,300	7,700	5.1%	0.1961
2020	6,632,200	525,700	41,400	23.5%	0.1689
2025	6,250,500	495,500	39,000	19.4%	0.1483
2030	3,769,400	298,800	23,500	10.3%	0.1307

Notes: 1) Per capita GDPs were forecast using time-series models described in Appendix E. The predicted per capita GDPs are in Table 9.1.
2) Values are rounded.

Table J2b. California tax collection impacts (Units: $M): South Dakota path and high enhanced drilling scenario

Taxes	2015	2020	2025	2030
Property	2,410	12,890	12,150	7,330
Sales and gross receipts	2,330	12,440	11,720	7,070
Individual income	2,050	10,940	10,310	6,220
Corporate income	410	2,170	2,050	1,240
Motor vehicle license	140	750	710	430
Other taxes	400	2,140	2,010	1,210
Total Taxes	7,700	41,400	39,000	23,500

Notes: 1) Units: $ millions.
2) Values are rounded.

Appendix K. Economic Modeling Scenarios

Fred Aminzadeh, Dan Wei, and Arman Khodabakhshnejad

The two enhanced-drilling cases employed in the economic modeling in this study are carefully formulated and historically based. These are as follows:

- A low "Adapted EIA Advanced-Technology Oil Drilling Scenario."
- A high "Projected Advanced-Technology Oil Well Drilling Scenario."

Adapted EIA Scenario for Advanced-Technology Oil Drilling for California

The first scenario was developed using data from the United States Energy Information Administration (EIA). The EIA *Annual Energy Outlook 2012* (EIA, 2012a) provides only a forecast on total California oil production. The total production numbers are not further disaggregated into total California conventional oil production and total California un-conventional oil production.

To calculate California conventional oil production, projected tight oil production for the Monterey Shale Formation in "EIA Petroleum and Biofuels Outlook" (EIA, 2012b) was examined. Monterey production is subtracted from the California total to derive California conventional production projections. These calculations are presented in the first three rows in Table K.1.

For the "Adapted EIA Advanced-Technology Oil Drilling Scenario", we apply the projected U.S. unconventional (advanced technology)-to-conventional production ratio to the California conventional production forecast to estimate the enhanced California advanced-technology oil production in the forecast years. The projected U.S. unconventional (advanced technology) and conventional oil production estimates are obtained from the EIA *Annual Energy Outlook 2012* reference case forecast (EIA, 2012a).

The EIA reference case forecast on unconventional (advanced technology)-to-conventional production ratio for the United States is presented in Row 4 of Table K.1. These ratios are then applied to the California conventional oil production numbers (in Row 3) to obtain the estimates of the enhanced California advanced-technology oil production numbers (shown in Row 5).

The incremental advanced-technology oil production for California is computed in Row 6. This variable is calculated as the difference between the total California oil production forecast with the enhanced California advanced-technology oil drilling forecast calculated in this scenario and the EIA base case California total crude oil production. The differential for this scenario, calculated by dividing the incremental advanced-technology oil production for California by the EIA base case California total crude oil production, is presented in Row 7. We further modified the differential for Year 2015 by assuming an exponential growth rate between Year 2010 and Year 2020.

Table K1. Calculation of the Adapted EIA Advanced-Technology Oil Drilling Scenario

	2015	2020	2025	2030
California Total Crude Oil Production (EIA forecast) (millions barrels per day) [*Row 1*]	0.49	0.47	0.48	0.47
Monterey (California) Tight Oil Production (EIA forecast) (millions barrels per day) [*Row 2*]	0.025	0.035	0.04	0.05
California Conventional Oil Production (millions barrels per day) [*Row 3 = Row 1 - Row 2*]	0.465	0.435	0.44	0.42
EIA Reference Case Unconventional (Advanced Technology) to Conventional Production Ratio for the U.S. [*Row 4*]	0.33	0.49	0.48	0.48
EIA Enhanced Advanced-Technology Oil Drilling Scenario for California (millions barrels per day) [*Row 5 = Row 3 × Row 4*]	0.15	0.21	0.21	0.20
Incremental Advanced-Technology Oil Production for California (millions barrels per day) [*Row 6 = Row 3 + Row 5 - Row 1*]	0.13	0.18	0.17	0.15
Differential [*Row 7 = Row 6/Row 1*]	26%	38%	36%	32%
Modified Differential	**6%**	**38%**	**36%**	**32%**

Projected advanced-technology oil well drilling scenario

This scenario was developed by Arman Khodabakhnejad, a Ph D student (under Prof. Fred Aminzadeh) at USC Viterbi School of Engineering, using data from published and unpublished industry sources. The conclusions reached under this scenario are derived from extremely limited data (limited decline curves). The results should be considered tentative and possibly very optimistic since other wells to be drilled in other fields (yet to be found) may not be nearly as productive. Many challenges remain for safe and economical exploration and production of Monterrey shale. As an example, see Brown (2012a) that features an interview with Prof. Aminzadeh where some the technical challenges are highlighted. In an another interview with Don Clarke and Tim Kustic, Brown (2012b) address this question: is Monterey shale a big deal or a big bust.

Background. Oil and gas production declines from the underground reservoirs through time due to reduction of reservoir pressure. Therefore, advanced production and reservoir engineering methods should be used to stop or even reverse the production trend. Enhanced oil recovery, stimulation, and drilling new wells are among the top techniques for increasing hydrocarbon production.

Viewed in production-engineering terms, oil and gas reservoirs undergo a natural evolution in productive capacity based on their initial pressure. If no artificial techniques have been applied, fluid production declines rapidly. Reduction of production in this condition can be modeled using appropriation estimation methods. All of these methods can be categorized under the name of “decline curve analysis.” This is very widely used technique for prediction of oil and gas production in time, considering only current number of wells.

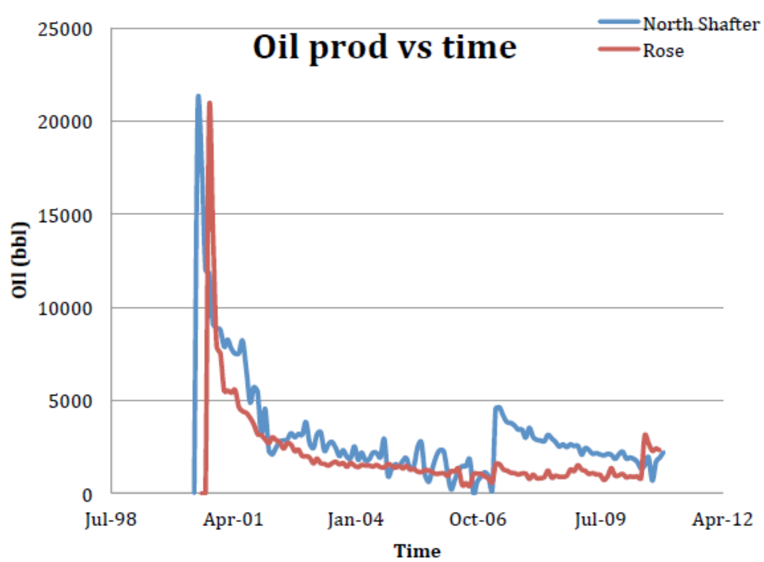
In this section, this method has been applied for projection of production at Rose Field and North Shafter Field. Also, the developed model for these Fields has been extended to predict production from Monterey Shale Formation in California. Description of Fields, technique, and the result are as follows.

Reservoir description. The productive part of Rose Field comes from the quartz phase a member of the McLure shale. The McLure transforms from Opal C/T to a quartz phase depends on temperature, pressure, and depth of burial.

The reservoir temperature is slightly lower in Rose Field than in North Shafter. True Vertical Depth (TVD) is 8,000 ft in Rose Field and 7,800 ft in North Shafter. The productive thickness is in the range of 20 to 40 ft. The reservoir produces well above the bubble point, with initial reservoir pressure of 6,300 psi. The pore pressure gradient is more than 0.8 psi/ft and reservoir temperature is 190 deg F.

Production performance. Overall performance of Rose and North Shafter Fields has been shown in Figure K1. As it can be seen from the figure, both fields follow the similar trend from beginning to end.

Figure K1. Oil production of Rose Field and North Shafter Field in 11-month intervals



In the North Shafter Field, for observation of the highest well producer, a consolidated plot of all the existing actively producing wells has been provided. The highest oil production belongs to 34-6H, which has produced at the initial rate of 560 stb/d and then in 2-year drops to 380 stb/d (Figure K2). In Rose Field, the most producible well was Purple Tiger 1H with the initial rate of 350 stb/d and declines to 80 stb/d in 2 years (Figure K3).

A well with higher water cuts will produce less oil and gas. The water cut for both North Shafter and Rose Fields have been around 40%. If decline curve of two fields are plotted, it can be observed that Rose Field has a smoother decline curve in comparison with North Shafter Field. If the decline curve slope is calculated for North Shafter, a decline rate of 10 bbl per year is obtained and, the same calculation shows 5.66 percent per year for Rose Field (Figure K4), but Estimated Ultimate Recovery (EUR) for North Shafter Field is higher than EUR for Rose Field.

Figure K2. Oil, water, and gas production at 34-6H

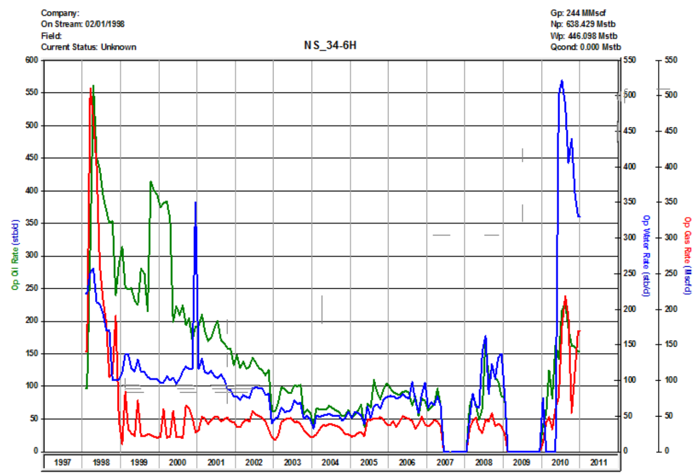


Figure K3. Oil, water, and gas production at Rose-1H

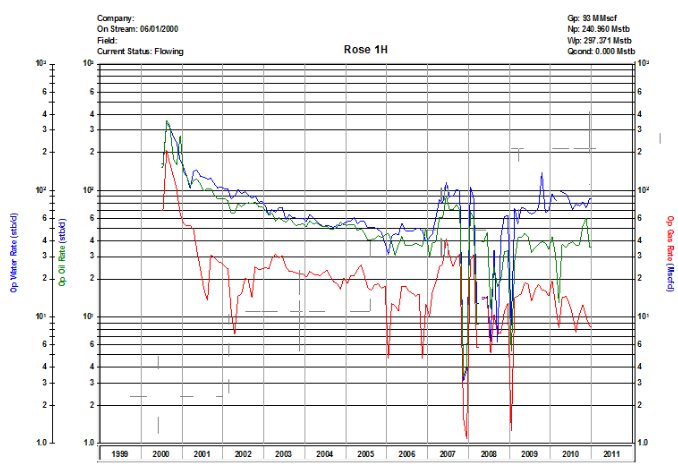
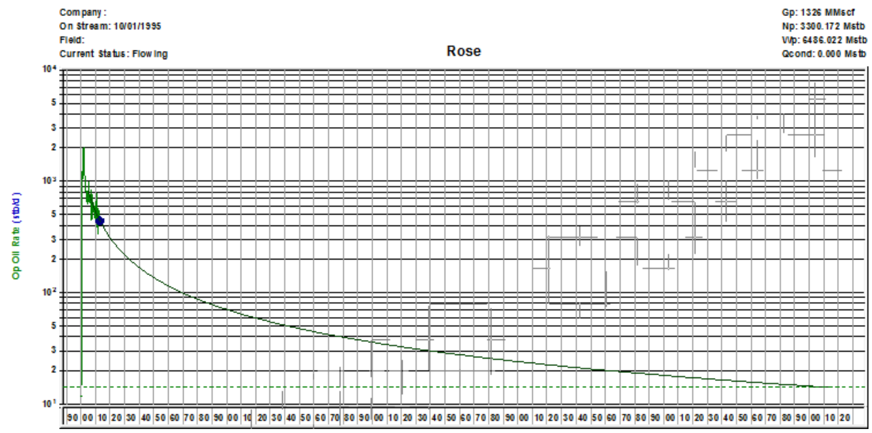


Figure K4. Oil production forecast for Rose-1H at Rose Field



Production forecast for the Monterey Shale. The Monterey Shale Formation, located at California's San Joaquin Valley, has been recognized as a huge and underdeveloped potential source of crude oil. Recent advances in horizontal drilling and hydraulic fracturing has changed the Monterey Formation from source rock to unconventional reservoir.

In this study, the results from Rose Field and Shafter Field—currently producing fields in the Monterey Shale Formation—have been extrapolated to predict future production from the Formation. Decline curve analysis was used above in order to model production from these two fields. Here, we apply same idea, and also including the drilling of new wells.

Two scenarios have been considered here: upper and lower production. In upper-production scenario, we assume that new wells produce as much oil as the old ones at the beginning of production. For the lower-production scenario, we add a degradation factor due to the reduction of production in new wells.

Two wells have been studied as typically producing wells in the reservoir. Production declines from these two wells (3-1 and RA1) are shown in Figures K5 and K6.

Figure K5. Oil production from well 3-1

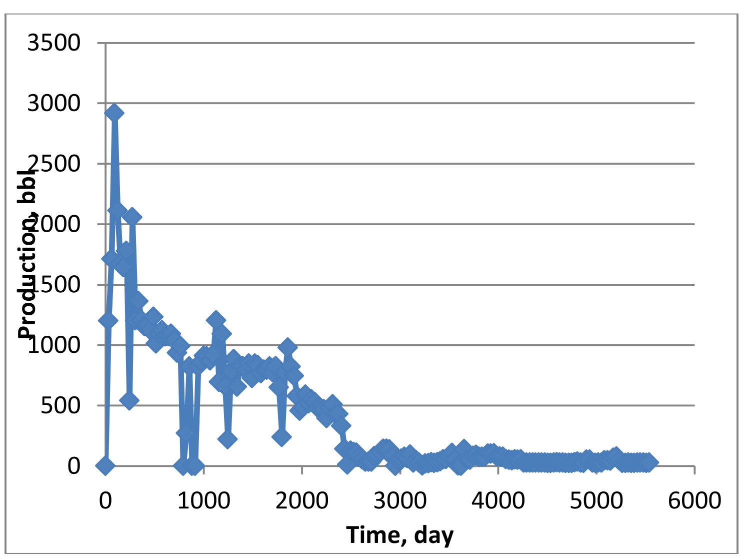
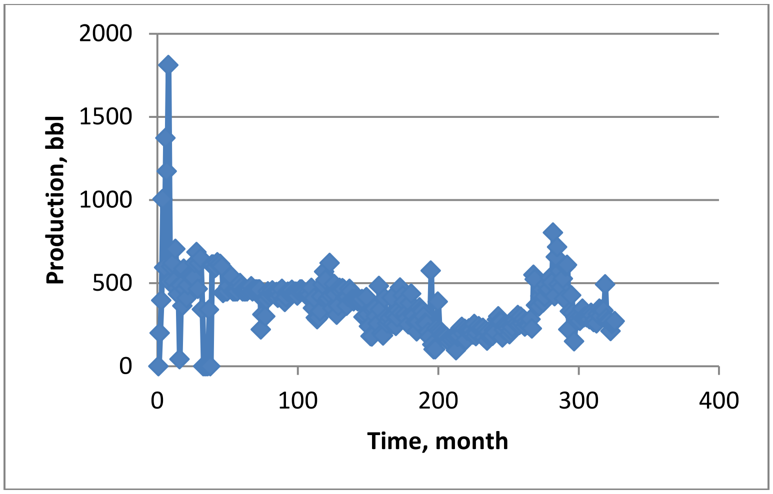


Figure K6. Oil production from well RA1



The estimated number of wells available as a source of future development from the field a given in Table K2.

Table K2. New well drilling plan in Monterey Shale Formation

Year	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Wells to be drilled	32	80	116	152	168	268	284	280	272	276

Year	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
Wells to be drilled	288	288	288	248	268	268	268	268	268	268	268	268	268

These values have been considered as reference values for drilling. However, some degree of uncertainty should be incorporated to increase the accuracy of the results. Using these values, the final production of fluid can be estimated. The results are given in Table K3.

Table K3. Production forecast in millions of barrel of conventional (advanced-technology) resources in California based on decline curve analysis method

Scenario	2015	2020	2025	2030
Decline Curve Analysis (1)	0.16	1.1	1.6	1.6
Decline Curve Analysis (2)	0.15	1.1	2.4	3.3
Modified Decline Curve Analysis (1)	0.15	0.69	0.67	0.42
Modified Decline Curve Analysis (2)	0.077	0.58	1.2	1.7

Decline Curve Analysis (1) in Table K3 is the result of using well 3-1. Decline Curve Analysis (2) is the result of using well RA1. Modified declined curve analyses are the result of applying a degradation factor.

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Research Team Bios

The Price School of Public Policy, USC

Peter Gordon. Dr. Peter Gordon is a Professor in the University of Southern California's Price School of Public Policy. Dr. Gordon's research interests focus on applied urban and regional economics. Dr. Gordon and his colleagues have developed various economic impact models that they apply to the study of the effects of infrastructure investments or disruptions from natural events or terrorist attacks. In addition, he continues to be interested in urban structure and economic growth, along with their associated public policy implications. He is the author of several books and more than 100 peer-reviewed journal articles in most of the major urban planning, urban transportation, and regional science journals. Dr. Gordon is a Fellow of the Regional Science Association International. He has consulted for local, state, and Federal agencies, the World Bank, the United Nations, and many private groups. He received the Ph.D. from the University of Pennsylvania in 1971.

JiYoung Park. Dr. JiYoung Park is an Assistant Professor in the Department of Urban and Regional Planning at the University at Buffalo. Dr. Park received his Ph.D. from USC in 2007 and was employed as a post-doctoral scholar developing applied economic models for national and regional infrastructure issues at the Center for Risk and Economic Analysis of Terrorist Events (CREATE). Dr. Park's research interests have focused on analyzing economic costs and resilience effects of shocks to urban and regional infrastructure and transportation systems, using applied econometrics and economic modeling techniques. Dr. Park has developed the National Interstate Economic Model (NIEMO), a spatially disaggregated operational Multiregional Input-Output model of the 50 states and Washington, D.C.

Dr. Park also has formulated various spatial and temporal extensions of this approach, which treats problems associated with urban and regional systems, integrating land use, transportation, the environment, and various economic aspects of the systems. NIEMO has been applied to simulating the multiregional freight movement system of the United States, analyzing detailed spatial impacts stemming from exogenous shocks such as climate change and/or localized disasters, and addressing multi-modal issues and multi-period problems. These models contribute to finding alternate predicted futures for use by various policy makers. Dr. Park has written two applied, practical econometrics textbooks, and is the author of two new books on economic modeling and empirical applications. Dr. Park has published more than 30 peer-reviewed journal articles and book chapters.

Adam Rose. Dr. Adam Rose is a Research Professor in the USC's Price School of Public Policy and the Coordinator for Economics at the USC's Center for Risk and Economic Analysis of Terrorist Events (CREATE). Before coming to USC, he served as the Head of the Department of Energy, Environmental, and Mineral Economics at The Pennsylvania State University. His research in the areas of energy and environmental economics cover a broad range of topics, including new energy technologies, energy and economic development, energy security, and climate mitigation policy.

His research has been sponsored by the National Science Foundation, U.S. Department of Energy, U.S. Bureau of Mines, U.S. Forest Service, U.S. Environmental Protection Agency, Southern California Association of Governments, California Air Resources Board, Wisconsin Public Service Commission, Pennsylvania Department of Environmental Protection, National Mining Association, American Petroleum Institute, Foster Wheeler, Inc., and Natural Resources Defense Council.

Dr. Rose is the author of several books and more than 100 peer-reviewed papers. He has served on the editorial boards of *The Energy Journal*, *Resource and Energy Economics*, *Energy Policy*, *Resources Policy*, *Pacific and Asian Journal of Energy*, and *Journal of Regional Science*. He is a recipient of the American Planning Association Program Planning Honor Award, Applied Technology Award for Outstanding Achievement, and the Regional Economic Models, Inc., Outstanding Economic Analysis Award.

The Communications Institute

John E. Cox, Jr. John E. Cox, Jr., is president and founder of The Communications Institute (TCI), a Los Angeles-based public policy research center, where he has served since 2003. He has coordinated numerous public policy research and education programs focused on such issues as energy, immigration, and state finance, many of which have been conducted in sponsorship with such academic and research institutions as the RAND Corporation, Caltech, Wharton Business School, the University of Southern California, the University of Arizona, and others. The researchers and program faculty for these initiatives have been drawn from leading universities and research institutes throughout the world, including such eminent institutions as the RAND Corporation and the Brookings Institution. Thousands of policymakers, including elected officials from both political parties on a national, state, and local basis, have led and/or participated in TCI sponsored programs.

Among The Communication Institute's work, Mr. Cox directed the original "Powering California" study in 2011, which examined the potential future energy scenarios for the State of California, and which documented the need for an "energy bridge" consisting of advanced fossil-fuel technologies that would take California into a more renewables-dominated energy portfolio in the decades ahead.

A former California journalist, Mr. Cox was President and founder of the Foundation for American Communications (FACS) for 27 years, which was the largest academic educator of journalists in the United States. The foundation educated more than 20,000 journalists in economics, science, business, land use policy, the environment, and law, led by faculty from such prestigious institutions as the John F. Kennedy School of Government, Harvard University, Yale Law School, Stanford University, and the University of California Los Angeles. Mr. Cox enlisted support for FACS from *The New York Times, The Los Angeles Times, Dallas Morning News, Chicago Tribune, Time*, CNN, NBC News, and media and nonprofit groups including Gannett, Hearst, Media General, Ford Foundation, MacArthur Foundation, and many others. Mr. Cox has written for numerous publications, including *The Los Angeles Times, USA Today,* and *The Arizona Republic.* Along with his extensive background in journalism, he has served as the Chief of Staff to both a United States Congressman and a California State Senator. He received his Bachelor of Sciences in journalism from San Jose State University.

Kevin Hopkins. Kevin Hopkins is Director of Research for The Communications Institute, a Los Angeles-based research center. Mr. Hopkins was co-author of The Communications Institute's 2011 "Powering California" study. He has served previously as Senior Economist for the White House Office of Policy Development, Director of the White House Office of Policy Information, senior policy counsel to the Federal Home Loan Bank Board and the White House Office of Science & Technology Policy, and as Senior Fellow at the Hudson Institute, a public policy research center. While at Hudson, he directed numerous major economic research projects funded by the U.S. Department of Labor, the U.S. Department of Health & Human Services, and the U.S. Department of the Navy. Among other work, he was research director for the U.S. Department of Labor's Workforce 2000 project, and oversaw the development of one of the first micro-simulated economic and behavioral models that correctly foresaw the course of the then-emerging AIDS epidemic.

For the past 22 years, Mr. Hopkins has been a senior contributing editor to Businessweek Magazine (now Bloomberg Businessweek), and has published five books and book-length research studies focused on economic issues, more than 100 articles and book chapters, and more than 50 national economic reports. He studied Ph.D. level economics at the University of Missouri and the University of California at Los Angeles, and has taught macroeconomics at the University of Missouri.