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Marine Hydrocarbon Seep Capture: Feasibility and Potential Impacts
Santa Barbara, California

A Group Project submitted in partial satisfaction of the requirements for the degree of
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by

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Abstract

Marine Hydrocarbon Seep Capture: Feasibility and Potential Impacts, Santa Barbara, California

The waters off of Coal Oil Point near Santa Barbara, California are home to some of the most active marine hydrocarbon seeps in the world. The recent energy crisis in California has sparked interest in capturing this seepage as a source of natural gas while reducing precursors to ozone formation. This study evaluates potential environmental consequences, regulatory aspects, and net economic benefits of capturing the natural gas. We find little positive or negative long-term impacts on the marine environment from installing seep tents. Additionally, we determine that beyond the required development permits, the major regulatory obstacles are permitting the gas processing infrastructure and acquiring emission reduction credits. The economic analysis requires assumptions regarding the number of seep capture tents, spatial distribution of flux, flux captured, ozone production, health benefits from reduced air pollution, future gas sales, and emission reduction credits. We design an integrated analytical model to evaluate the costs, benefits, and ultimate economic viability of a seep tents project under varying assumptions. Under our "most likely scenario" we project total costs of $7.5 million, monetary health benefits of $2.1 million and gas sales revenue of $2.2 million, resulting in a total project loss of $3.1 million over a 20-year planning horizon. To explore parameter sensitivity, we run a comprehensive sensitivity analysis. Results suggest that the project becomes economically attractive only when emission reduction credits are issued. Given present political, economic, and seep flux conditions we find that installing seep tents is not economically profitable and that health benefits from ozone reduction are unlikely to justify further tenting of the marine hydrocarbon seeps in the Santa Barbara Channel.

Executive Summary

Marine Hydrocarbon Seep Capture: Feasibility and Potential Impacts, Santa Barbara, California

By: Ali Ger, Misty Gonzales, Erin Mayberry, Farah Shamszadeh[1]

Significance
Just off of Coal Oil Point near Santa Barbara, California lie the world's most active and most studied marine hydrocarbon (oil and gas) seeps (Figure 1) (*1*).

Figure 1: Map of Southern California showing study area. Source: UCSB Hydrocarbon Seep Project (2001).

The recent energy crisis in California has renewed interest in capturing this seepage as a potential "green" source of natural gas. The Santa Barbara County Air Pollution Control District (SBCAPCD) believes that capturing natural hydrocarbons may reduce local air pollution.

Background
ARCO Oil and Gas Company installed the world's first seep gas capture devices in 1982 (*2*). The two tents currently capture enough natural gas to provide energy to 190 households per year (*3*).

Capturing the seep gas and routing it to commercial pipelines provides an exciting alternative to more traditional natural gas development. The seeps are also one of the most unique sources of air pollution in the nation because the seep hydrocarbons contribute to ground level ozone (smog).

Problem Statement
In this study we analyze the environmental consequences, political feasibility, and economic practicality of installing additional seep tents in the Santa Barbara Channel.

Research Approach
We take an interdisciplinary approach to evaluating a proposed project by estimating the:
- Water quality and marine ecological impacts
- Effects on air quality
- Regulatory obstacles and requirements
- Economic costs and benefits of installing additional seep capture tents.

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[1] Advisors: Assistant Professors Christopher Costello and Natalie Mahowald.

Below, we outline the key findings of our integrated analysis, concluding with the economic criteria necessary to make a seep tents project practical. We list recommendations for further research, potential seep tents projects, and policy regarding their use in the Santa Barbara Channel.

Environmental Impact

A seep tents project will likely have a minimal long-term impact on water quality and marine ecosystems, and will generate small improvements in air quality, as outlined below.

Effect of Seep Tents on the Marine Environment

In order to estimate the effects of seep tents on the marine environment, information on the biogeochemistry and marine ecology of the Coal Oil Point seeps are synthesized. Figure 2 shows the most recent mapping of the seep field's hydrocarbon flux.

Most of the hydrocarbons released by the seeps dissolve, disperse and/or biodegrade before they have a detectable impact on water quality and marine ecosystems. A unique benthic community is adapted to the seep sediments where toxicity-tolerant bacteria decompose and use seep hydrocarbons. These hydrocarbons then enter the food chain through organisms that prey on the bacteria, resulting in increased biomass in the seep community (*4*).
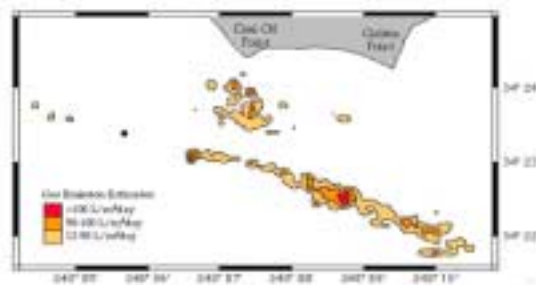

Figure 2. Hydrocarbon Seep Area Map. Source: UCSB Hydrocarbon Seep Project (2001).

There will be little impact to benthic organisms if the seep tents are raised off the sea floor. Most of the environmental impacts from tent installation would be short term, one-time impacts to the seafloor communities; however, laying pipeline could cause long-term ecosystem level impacts if not placed sufficiently far from critical habitats such as kelp beds.

Overall, we estimate no benefits or significant impacts on the water quality and marine ecology from installing additional seep tents off Coal Oil Point.
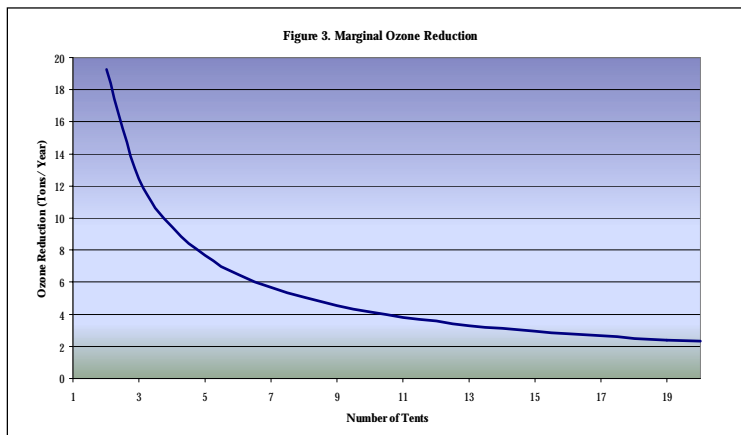
Effect of Seep Tents on Air Quality

We develop an air quality model that relates seep gas emissions to ozone formation and estimates the change in ozone associated with seep gas capture (*5*). This links to a health impacts model that monetizes the benefits of improved air quality from seep tents installation.

The seeps release reactive organic gases (ROGs) into the atmosphere that react with oxides of nitrogen and sunlight to form tropospheric ozone (smog). Ozone is a serious health concern, yet the seeps' contribution to ozone formation is small compared to other sources. Because of the complex chemistry of ozone formation, the magnitude of the seeps' contribution depends on the climate and the spatial and temporal levels of ROGs and nitrogen oxides in Santa Barbara's airshed, and can vary considerably.

The first seep tent will reduce about 0.4% of total ozone produced annually in Santa Barbara County, averaged over 20 years, as opposed to 41% produced by man-made sources (*6*). Statistical analysis of spatial heterogeneity of seep flux shows that additional tents reduce less ozone on the margin (Figure 3).

Methane, the primary component of seep gas, is a potent global warming agent; methane from the seeps accounts for roughly 0.004% of global emissions (7). One seep tent -would reduce approximately 0.0003% of global methane emissions.

Figure 3. Marginal Ozone Reduction

(line graph: Ozone Reduction (Tons / Year) on the y-axis ranging 0 to 20, Number of Tents on the x-axis ranging 1 to 19)

Regulatory Requirements

Aside from the required development permits, the major regulatory obstacles are permitting the infrastructure to process the gas and acquiring emission reduction credits.

Permits and Gas Processing

Permits and approval for installing tents and infrastructure are required from the California EPA, Army Corps of Engineers, State Lands Commission, Coast Guard, S.B. County Planning and Development, and SBCAPCD (8). Gas processing will most likely require an onshore facility. Current regulations under the Santa Barbara County Coastal Plan present an obstacle to sending seep gas to a new or existing onshore facility.

Emission Reduction Credits

Emission reduction credits (ERCs) may be allocated to polluting firms in agreement with the SBCAPCD, allowing the firm to emit certain amounts of polluting substances in return for reducing polluting emissions elsewhere. ERCs were critical to the economic success of the 1982 ARCO project and are currently valued at about $4,000 per ton of ROGs (9).

For two primary reasons, it is unlikely that the project will receive federal emission reduction credits: (1) an applicant must show the reductions are permanent, yet the seepage varies over space and time, and (2) as a natural emitter of ROGs, capturing the seep gas is not currently eligible for federal credits. Given these factors, it would be an exception for the U.S. Environmental Protection Agency to issue credits for a seep tents project.

Cost-Benefit Analysis

A formal accounting of the costs and benefits of a seep tent project will guide regulators in decisions regarding the project. Thus, two views are taken in evaluating the economic results: that of the entrepreneur and that of the policymaker. The entrepreneur needs to know the project profit, which equals the revenues from natural gas sales and ERCs, less the capital, installation, and maintenance costs over a 20-year planning horizon. In addition to considering entrepreneurs

incentives the policymaker must also consider the value of improved air quality. If the project is acceptable, the policymaker must also determine the appropriate amount of ERCs required to create an incentive for seep tent installation.

An integrated analytical model is developed to simulate over 17,000 different project scenarios and determine their viability from the entrepreneurial and social perspectives. The cost-benefit analysis model integrates the ozone reduction model, health benefit valuation model, emission reduction credits, gas price forecast and project cost estimates. Four methods of forecasting natural gas prices are used. The most likely forecast is an annual average generated by an ARIMA time series model, valued at $2.45 per 1000 cubic feet (MCF). The value of improved health from ozone reduction is determined using a range of studies from the economic literature, and results in three scenarios. The most likely scenario values health benefits at $2.1 million for the first tent averaged over 20 years.

Most-Likely Project Scenario

A most likely project scenario is constructed of conservative parameters based on the best available data (shown in Table 1).

Input Parameter	Value	Source
Starting Tent Flux Capture	220,000 MCF/tent/year	ARCO starting tent Capture
Decrease in Flux Over Time	7.4%	Historic ARCO Capture
Discount Rate	5%	Intermediate Estimate
Gas Sales Scenario	Conservative	ARIMA Time Series Model
Health Benefit Scenario	Conservative	Benefits-Transfer Approach
Air Regime (NOx or ROG limited)	Co-limited (NOx-ROG)	Ozone Production Model
Emission Reduction Credits	No	SBAPCD Judgment

Table 1. Most likely project scenario parameter values and source of values.

Under the "most likely scenario" we project present value costs of $7.5 million, monetary health benefits of $2.1 million, and gas sales revenue of $2.2 million resulting in a total project loss of $3.1 million over a 20-year planning horizon (Figure 4). Health benefits and emission reduction credits are the model's most influential parameters based on a sensitivity analysis of the project's value and profit.
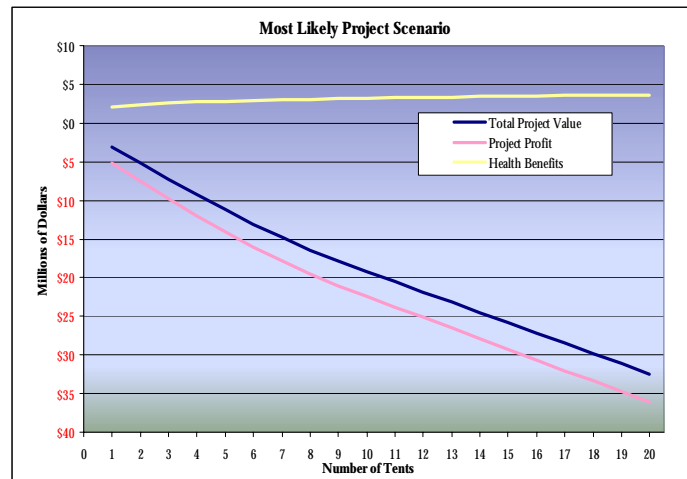
Five other project scenarios (Table 2) show that:

- No seep tents should be installed even with the maximum effect of the tents on ozone reduction
- Both high and scarcity-driven gas pricing suggest that one tent should be installed
- Five tents are optimal under the least conservative health benefits valuation method
- Three tents are optimal if emission reduction credits are acquired

Table 2. Summary of results: optimal number of tents, project value, health benefit, and project profit for six project scenarios (Millions of dollars).

Scenario	Description	Optimal Tents	Project Value	Health Benefit	Project Profit
Most-likely	Most-likely	0	$0	$0	$0
		(1)	(-$3.1)	(+$2.1)	(-$5.2)
1	ROG-limitation	0	$0	$0	$0
		(1)	(-$1)	(+$4.2)	(-$5.2)
2	High Gas Pricing	1	$4.3	$4.2	$0.1
3	High Gas Pricing/ Health Benefits	5	$41.3	$48.2	-$6.9
4	ERC	3	$32.6	$2.6	$30
5	Hotelling Gas Pricing	1	$0.2	$2.1	-$1.9

Under likely project conditions, installing new seep tents is not practical from either a social (public policy) or an entrepreneurial viewpoint. From a business' point of view, unless emission reduction credits are issued or unlikely high market gas pricing conditions are sustained, the project will not be attractive. From society's point of view, the most likely scenario is not valuable because costs to the private firm are greater than society's benefits.

If a potential project's value were positive, however, a policy could be devised to motivate installing seep tents. ERCs could be issued to compensate an entrepreneur for their losses on the project. For example, in a low-cost version of the most likely scenario, the project loses $1.7 million (without credits). For a credit of only 5% of this project's ROG reduction (the 1982 ARCO project used 80%), the owners of the tents would be compensated $2 million for this loss and would achieve an industry standard 10% rate of return. This suggests that a policymaker could create an incentive to produce an air quality improvement valued at $2.1 million for $2 million in emission reduction credits.

Before issuing credits it is prudent to compare the cost effectiveness of installing seep tents to other abatement technology. Results suggest that seep tents are a cost effective technology for ROG abatement ($1,800 with seep tents vs. $5,000/ton using other abatement technologies) (10). However, the seep tent's potential to abate methane emission is not sufficient to justify the project ($550/ton with seep tents vs. $ 3.80 /ton on the global trading market) (11).

Recommendations

Further Research

Research should be conducted to better understand the chemistry of the Santa Barbara airshed as well the marine ecology of the seep field. We recommend the use of Santa Barbara County hospital data to derive the exact relationship between illness and ozone in place of using a benefits transfer method.

Project Recommendations

If a seep tents project is proposed in the future, we recommend that an entrepreneur consider the following points: (1) permitting associated with onshore gas processing, (2) acquisition of ERCs.

Policy Recommendations

A policymaker should evaluate the following four issues in light of a new seep tents project: (1) the precise amount of ozone reduced by seep tents should be calculated to accurately determine the value of health benefits and amount of emission reduction credit; (2) permit conditions should account for the seeps' spatial and temporal variability; (3) a socially responsible value for the credits should be instituted that is equal to or less than the health and other possible external benefits of ozone reduction by seep tents; (4) the cost effectiveness of seep tents should be compared with other methods of abating tropospheric ozone.

References and Notes
1. D. C. Quigley, *Quantifying Spatial and Temporal Variations in the Distribution of Natural Marine Hydrocarbon Seeps in the Santa Barbara Channel, California*, Geology Department, UCSB (1997).
2. B. Rintoul, *Pacific Oil World*, 74, 6 (1982).
3. Household gas use from the U.S. Department of Energy at www.eia.doe.gov/emeu/consumptionbriefs/recs/natgas/year.html.
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Chapter 1: Research Motivation

1.1 History of Seep Tents in the Santa Barbara Channel

Oil and gas have been seeping from the earth into the sea for thousands, if not millions of years, and the northern margin of the Santa Barbara Channel is currently one of the most active seepage sites in the world (Quigley, 1997; Egland, 2000; Boles, Clark, Leifer, & Washburn, 2001). Before colonization, Native Americans used the oil and tar slicks from the seeps to waterproof their canoes. European explorers first noticed the seepage in 1792 (Fischer & Stevenson, 1973). Captain Cook's navigator, George Vancouver described the seeps: "The sea had the appearance of dissolved tar floating on its surface, which covered the sea in all directions" (Guthrie, Rowley, & ARCO Oil and Gas Co., 1983; Fischer & Stevenson, 1973). The description is still accurate today. Oil slicks and mats of tar can be seen floating on the surface of the ocean, and the water boils with bubbles of escaping gases in the vicinity of the seep vents. Tar is common on local beaches, and fumes from the seeps can often be detected from shore. The seeps are not an isolated local phenomenon. They have been observed near shore from Point Conception to the Gulf of Mexico (Fischer & Stevenson, 1973). Marine hydrocarbon seepage is common throughout the world in soft bottom basins overlying oil and gas reserves, such as the Gulf of Mexico, Persian Gulf, and offshore areas of Venezuela and Alaska (Quigley, 1997).

Seeps off of Coal Oil Point near the University of California, Santa Barbara, emit both liquid and gaseous hydrocarbons from more than 250 seafloor vents, about half the seepage along the northern Channel. Seep oil and gases flow up through the stratified layers of rock along the geologic fault zones to the seabed where they are injected into the water column (Clark, Washburn, Hornafius, Luyendyk, & Ho, 1996). The seep gas flowing out of the seabed is between 87 to 90 percent methane, followed by ethane, propane, and traces of heavier hydrocarbons like pentane and benzene (Clark, Washburn, Hornafius, & Luyendyk, 2000). Quigley (1997) and Hornafius, Quigley, and Luyendyk (1999) estimate the total methane flux from the ocean to the atmosphere to be between 2-5 x 10^{10} grams per year. Variation in seepage through space and time is an important characteristic of the Coal Oil Point Seeps and they should be viewed as dynamic systems (Quigley, 1997) . Research has also correlated a reduction in seepage rates near offshore oil platforms with reduced reservoir pressure beneath the seeps due to oil production (Quigley et al., 1999). Even so, the Coal Oil Point seeps are still the main source of surface methane concentration in the Southern California Bight, the marine ecosystem from Point Conception to northern Baja California (Cynar & Yayanos, 1992; Clark, Washburn, Hornafius, & Luyendyk, 2000).

In the early 1900s technology developed that could extract raw fuels from hydrocarbon reservoirs in the Santa Barbara Channel. For the first half of the 20th century, oil was extracted throughout Southern California via offshore platforms. Since the mid-1960s, ARCO Oil and Gas Company had been operating in the Santa Barbara Channel. In the late 1970's the company began exploring a project that did not involve drilling from an

offshore platform. The project involved collecting the naturally seeping gas and oil to sell. In exchange for reducing the seeps' hydrocarbon emissions, ARCO received pollution reduction credits to mitigate another development project. The seep tents project was the first containment of natural marine seeps on record (Rintoul, 1982).
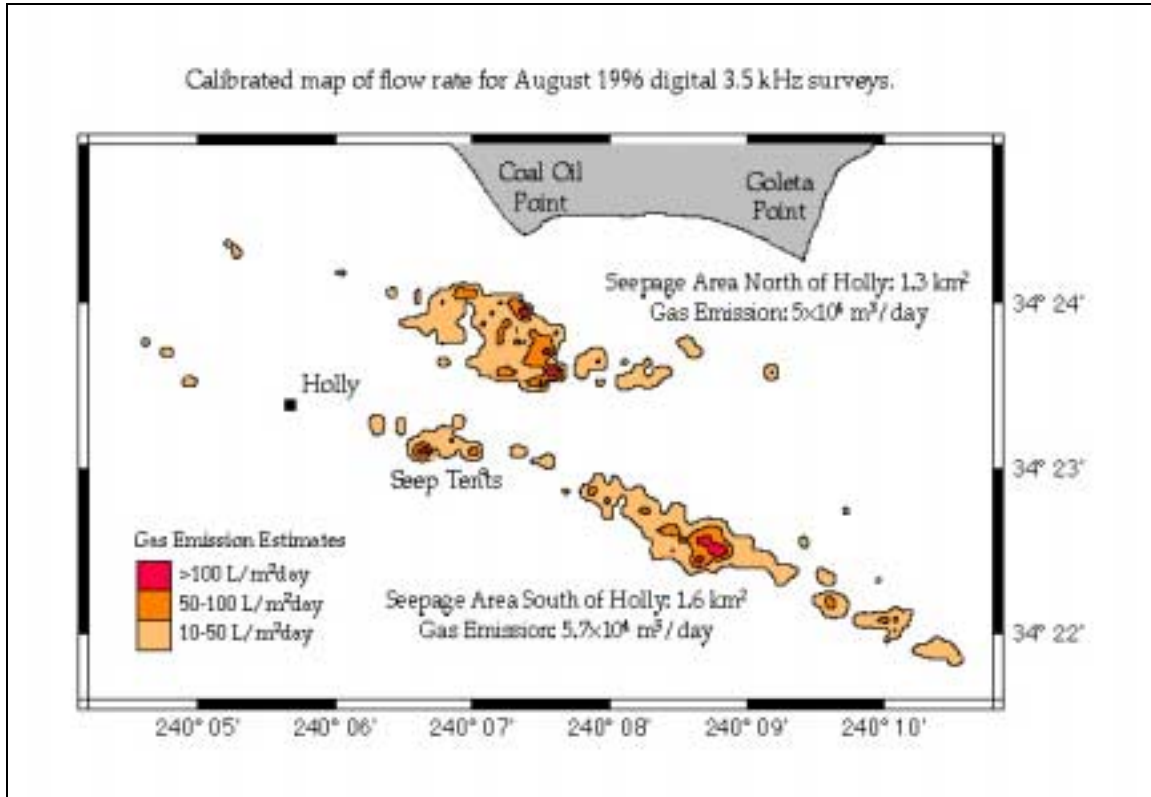
Figure 1. Hydrocarbon seep area off Coal Oil Point. Map illustrates seepage rate estimates, and the two seep tents installed by ARCO in 1982. Source: UCSB Hydrocarbon Seeps Project (2001).

Figure 1 depicts the seep field, which is located in 20 to 60 meters of water within a few miles of the shoreline (UCSB Hydrocarbon Seeps Project, 2001). Data was obtained from sonar surveys, and map shows only the general seepage areas. Smaller scale flux estimates are not shown. In order to maximize the capture of gas and oil, ARCO chose the location with the most active seepage to place the tents. This site was located on State Lease PRC 3242, which was jointly owned by ARCO and Mobil Oil Corporation (Guthrie, Rowley, & ARCO Oil and Gas Co., 1983). The project required permits from the State Lands Commission, the State Coastal Commission, and Santa Barbara County (Rintoul, 1982).

Capturing naturally seeping gas and oil had never been attempted; consequently engineering a "seep tent" was an important component of the project. The design was intended to optimize the seep gas capture and create a sturdy structure. It sought to cover one half-acre of vent area and have the ability to withstand tidal, earthquake and storm forces. The engineering resulted in two steel and concrete pyramid-shaped tents that are

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each 100 by 100 feet wide and 20 feet tall with a cylindrical oil and gas separator attached to the top. Both are held in place by twelve 25-ton concrete blocks, in addition to each pyramid's own 350 tons of weight (Rintoul, 1982; Guthrie, Rowley, & ARCO Oil and Gas Co., 1983). A pipeline was installed specifically for the tents, which sent the collected gas to ARCO's Ellwood processing plant, now owned by Venoco, Inc. The six-inch diameter pipeline runs four miles from the tents to the plant (Rintoul, 1982).

ARCO had spent more than $7 million dollars on the project by the end of 1982 (Rintoul, 1982). However, ARCO's Guthrie and Rowley wrote in their summary that, "This project would not have been attractive economically without incentives. The daily gas production rate is not substantial enough to be a break-even venture, let alone be profitable"(1983).   It was the issuance of emission reduction credits that motivated the venture.

The U.S. Environmental Protection Agency enacted legislation in 1976 that allowed polluting emissions to be offset by separate pollutant reductions. The state of California adopted this policy, and it became central to the success of ARCO's seep tents project. ARCO received emission reduction credits for implementing the seep capture project, allowing "interpollutant tradeoffs" where the Santa Barbara County Air Pollution Control District required them to remove 1.2 parts hydrocarbons for each part of nitrous oxides (NO_x) emitted to the atmosphere in future development projects (Rintoul, 1982).

ARCO claimed there was an environmental benefit from capping the seeps. Currently, the two tents capture about 10% of the total gas seepage from the Coal Oil Point seep field (Bartsch et al., 1996). Craig Strommen, an engineering supervisor from the county's Air Pollution Control District said in 1982: "We feel that the containment of this seep will result in a significant reduction in the amount of uncontrolled reactive hydrocarbons and oil emitted into the environment of Santa Barbara County" (Rintoul, 1982).

1.2 Significance

Installing seep tents is attractive for two reasons: first, the significant amounts of reactive hydrocarbons emitted by the seeps are considered to be a natural source of air pollution by the Santa Barbara County Air Pollution Control District (SBCAPCD) ([SBCAPCD-1], 1998). Seep gas contains reactive organic gases, or ROGs, which cause the formation of tropospheric ozone when combined with NO_x gases and sunlight. Capping the seeps would reduce ROG levels, and could reduce ozone levels depending on the local air regime. Second, the recent energy crisis in California has sparked interest in installing additional tents off Coal Oil Point to capture seep gas as a source of natural gas. The seep field offshore of University of California, Santa Barbara (UCSB) releases an amount of methane estimated to be twice UCSB's energy demand of natural gas.

The greenhouse gas methane comprises 80 to 90 percent of the seep flux (Hornafius, Quigley, & Luyendyk, 1999). Greenhouse gases are those that act to trap heat in the earth's atmosphere and cause global warming. The Intergovernmental Panel on Climate

Change (IPCC) defines a gas's potential as a greenhouse gas by its potency relative to the most abundant greenhouse gas, carbon dioxide; methane is about 25 to 62 times more potent. Because climate effects are an important consideration in energy policy, this report will also evaluate the impact of the seeps, and difference resulting from tenting the seeps if any, in global climate change.

In this light, we evaluate the potential to install additional tents in the Santa Barbara Channel in terms of the environmental consequences, economic costs and benefits, and regulatory framework. The conclusion of this report resolves several uncertainties surrounding installing additional seep capture tents, and will contribute significantly to a well-informed decision. The results of this study can be compared to other air pollution control methods to reach a cost-effective decision.

1.3 Research Question

Is it environmentally advantageous to install additional seep tents to capture naturally released hydrocarbons? Further, is it economically practical and politically feasible to install additional seep tents?

In Part 1 of this report we examine the potential impacts on the marine ecosystem and air quality due to developing marine hydrocarbon seeps in the Santa Barbara Channel. Within Part 1, Chapter 2 summarizes the effect of seep tents on the water quality and marine ecology of Coal Oil Point. Chapter 3 explores the effects of seep capture on air quality and climate. Part 2 of this report focuses on the political and economic practicality of seep capture. Chapter 4 presents the regulatory requirements of installing seep capture tents. Chapter 5 assesses the economic practicality of installing seep capture tents in a cost-benefit analysis. Chapter 6 discusses the main findings and conclusions of the report, and lists our resulting recommendations.

PART 1: Marine and Air Impacts from Developing Marine Hydrocarbon Seeps in the Santa Barbara Channel

Is it environmentally advantageous to install additional seep tents to capture naturally released hydrocarbons? In Chapters 2 and 3, we discuss the two major environmental impacts of the marine hydrocarbon seepage: its effects on the marine ecology of Coal Oil Point and the air quality of Santa Barbara County. We also discuss the potential impacts of developing the seeps using seep tents.

Chapter 2: The Effects of Marine Hydrocarbon Seepage on the Marine Ecology of Coal Oil Point

2.1 Introduction

An essential component of this project, and the goal of this section is to estimate the impacts of additional seep tents on the marine ecology and water quality of the waters off Coal Oil Point. To accurately estimate the impacts of seep tents, it is necessary to understand the current biogeochemistry and marine ecology associated with the seep hydrocarbons. Information on the marine ecology and water quality explains the patterns of life associated with the seeps and how the seeps affect the water quality. These processes must be well understood in order to determine how the tents will alter and impact the marine environment.

A well-informed decision about the seep tents must include defendable estimates of their marine impacts. Once the current patterns and processes associated with the seeps are explained, how the tents and infrastructure are expected to change and impact the marine environment is evaluated. From the combination of such information we estimate the marine impacts of additional tents based on the attributes of the proposed project and similar projects in the past.

Section 2.2 explains the general water circulation in the Santa Barbara Channel as it affects the seeps plumes. Section 2.3 provides various estimates of the seep flux from the ocean floor into the water and atmosphere, and section 2.4 establishes the fate and transport of seep hydrocarbons in the water column. Section 2.5 details the ecology of the seepage area as it relates to impacts from the additional tents. Sections 2.6 and 2.7 predict the impacts of additional seep tents on the seep flux and the marine environment respectively. All of these topics are closely interrelated and directly concern this project. Natural variation in the seep flux and location not only affects the ecology of marine species, it also dictates where ideal future tent sites should be. Similarly, without a clear understanding of the biogeochemistry and sediment ecology, it is not possible to determine the potential impacts of the tents on the marine environment. The topics explained below progress from explaining the general oceanography of the Santa Barbara Channel, to smaller scale geo-chemical flows and ecosystem level processes and considerations concerning the seep area.

2.2 Santa Barbara Channel Water Circulation

Water circulation in the Channel affects the currents near the Coal Oil Point seep field, which in turn determine the direction of the seep plumes. Studies looking at the characteristic patterns of the surface currents in the Santa Barbara Channel (Channel) show that the near shore currents in the seep study area are a superposition of two large-scale flows, which change direction seasonally. There are two dominating and well-defined currents off the coast of Southern California that affect the water circulation in the Santa Barbara Channel (see

Figure 2). These are known as the California Current, an equator-ward, cold-water current, and the Southern California Counter Current, which is warmer and pole-ward. The California Current branches shoreward and then pole-ward (north) in the Southern California Bight, joining the warmer Southern California Countercurrent, which reaches its seasonal maximum in winter. Often, an eddy-like cyclonic circulation forms within the Channel (otherwise known as the Southern California Eddy) with a seasonal maximum in summer to early fall. Together the eddy and currents affect the general flow within the Santa Barbara Channel. This flow is generally equator-ward in spring, and pole-ward from summer through winter, with seasonal and climatic anomalies (Harms & Winant, 1998).

After Hickey, B. M., 1992, Progress in Oceanography, V30: 37-115.
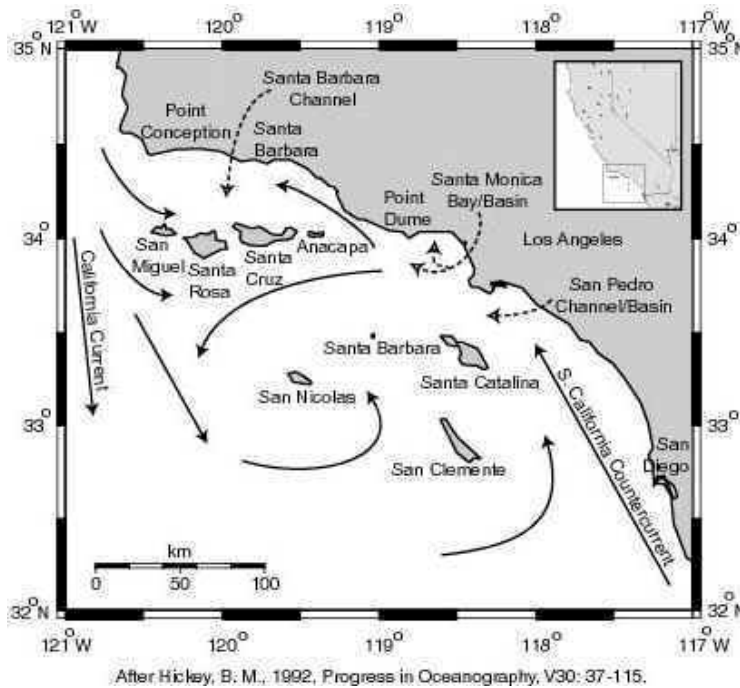
Figure 2. General water circulation in Southern California. Source: (California State University Long Beach Department of Geological Sciences [CSULB], 2001).

The sub tidal near surface circulation in the Santa Barbara Channel affects the transport and extent of the distribution of the seep plumes (Clark, Washburn, Hornafius, & Luyendyk, 2000). Though the general patterns of circulation are predictable, smaller scale (temporal and spatial) variations in the currents exist. For example, during the middle of summer, in 1999, the direction of the water flow off Coal Oil Point reversed as seep monitoring research was conducted (Clark, Washburn, Hornafius, & Luyendyk, 2000). This variation makes it difficult to predict and measure the flux, sea floor flux (and location) of the seeps, and horizontal displacement of the seep plumes.

2.3 Seep Hydrocarbon Flux

It is important to understand the rates of seep flux from the sediments to the water column. Without knowing the amount of seep hydrocarbons entering the water column, predicting the impacts from reducing this flux would not be possible. This section provides background information on the seeps geology, and the various estimates of seep flux including the flux from sediments to the water, and water to atmosphere. Seep hydrocarbons escape from subsurface reservoirs through fractures and pores in sedimentary rocks as a mixture of free gas, dissolved gas, oil, heavier hydrocarbons and water (Boles, Clark, Leifer, & Washburn, 2001). The Coal Oil Point Seeps emit liquid and gaseous hydrocarbons from more than 250 seafloor vents, though the number of individual vents, location and seepage rates are variable (Davis & Spies, 1980). This is estimated as about half the seepage along the northern Channel.

Analysis of the data suggests that the total gas seepage from the Coal Oil Point Seep Field is on the order of 8-20 x 10^4 m^3 gas per day. About half of the seep hydrocarbons dissolve by the time they reach the ocean surface (Luyendyk, 2001). The seep gas that escapes from the ocean floor is mostly methane (about 87%), followed by ethane and propane, along with traces of heavier hydrocarbons like pentane and benzene (Clark, Washburn, Hornafius, & Luyendyk, 2000). These hydrocarbons include compounds that are considered as reactive organic gases (ROGs) once they enter the atmosphere and, depending on the airshed chemistry, can act as air pollutants. It is estimated that the total methane flux from the ocean to the atmosphere is between 2-5 x 10^{10} g/yr (Quigley, 1997, and Hornafius, Quigley, & Luyendyk, 1999). Methane released from the Coal Oil Seeps accounts for between 0.001 to 0.004% of total global methane production (see Section 3.9).

Seep hydrocarbons released into the water column are transported away from the seep field into the regional waters along the density surfaces (Clark, Washburn, Hornafius, & Luyendyk, 2000). The direction of the transport depends on the currents, which generally can be eastward or westward. Seep hydrocarbons are transported down current, where they become oxidized or diffused through the thermocline and are lost to the atmosphere via gas exchange. About 2.1 x 10^{10} g/yr of methane is injected into the water column above the Coal Oil Point Seeps (Clark, Washburn, Hornafius, & Luyendyk, 2000). Mass balance calculations for methane indicate that about half of the methane (25%-60%) coming out of the seep vents dissolves in the water column before reaching the water-air surface. About 50% of the gas dissolves in the water column (Luyendyk, 2001). The latest seep flux estimate was done using a gas capture buoy instead of sonar surveys, and this suggests an estimated total flux for the same seep field of 8(±4) x 10^4 m^3 gas/day, which is on the same order of magnitude as the sonar survey estimates (Egland, 1999). However, there are several different, independent estimates of the total flux from the Coal Oil seep field, as shown in Table 1 below.

The composition of the seep gas at the surface is not known and a complete mass balance for methane in these waters is not possible because other seep inputs and the oxidation rate within the water column is not known. Studies show that seepage into the stratified coastal waters off Isla Vista created plumes that extend for at least 12 km. The plume structures are complex because of the large geographical distribution of seep vents and the chaotic nature of advection and mixing (Clark, Washburn, Hornafius, & Luyendyk, 2000). However, these studies have important temporal limitations as the conclusions are based on a one-time (3-day) cruise, during summer (high stratification), so there is no temporal variation in the data.

Table 1. Summary of different seep flux estimates for the Coal Oil Point Seep Field

Estimates for Total Seep Field of Coal Oil Point	Seep Gas (m^3/day)	Methane (metric tons/day)	Non-methane Hydrocarbons (metric tons/day)	Liquid Petroleum (liters/day)	ROG Evaporation from Oil (metric tons/ day)
Fischer, 1973	5.1×10^4	22.6	7.5	4590	2.0
50 kHz sonar*	9.9×10^4	48.8	14.5	8910	4.0
July-Sept 1995*	20.3×10^4	90	29.8	18,270	8.1
August 1996*	10.7×10^4	47.5	15.7	9630	4.3
Egland, 1998-1999 (bouy surveys)	$8(\pm4) \times 10^4$	-	-	-	-

* Data from Quigley, 1997

2.3.1 Natural Variation of the Seep Field

Seepage rates and locations change through time (Boles, Clark, Leifer, & Washburn, 2001; Stuermer et al., 1982). For example, the seeps which have tents on them today were first visually observed on the sea surface about 1.6 km southeast from the oil platform Holly in 1970, apparently as bubbles started surfacing offshore Holly. The seeps disappeared shortly thereafter, and reappeared almost twice as active on June 4, 1973. After this second and more persistent appearance, ARCO decided to install the two steel tents to capture the seep gas (Boles, Clark, Leifer, & Washburn, 2001). Variation in seep flux (spatial and temporal) for the Coal Oil Point seeps continued after the tents were installed. Most of the seepage moved outside the tents after a few years of installation. The tents were expanded in order to capture the shifting seep gas (Boles, Clark, Leifer, & Washburn, 2001).

Few studies have looked at the natural variation of seepage both through space and time (Boles, Clark, Leifer, & Washburn, 2001). Recently, Boles, Clark, Leifer, and Washburn (2001) monitored the seep flow rate hourly for over 9 months from the two steel tents

installed by ARCO in 1982 in order to estimate the variability in seepage rate over time. This is the first high quality time series of seepage rates from the Coal Oil Point. The data suggest that seepage rates are affected by tides; high tidal height correlates strongly with decreased seepage rates (and vice versa), and analysis of the time series data shows clear tidal cycles. It is hypothesized that increased tidal height puts more pressure on the ocean floor, which reduces the individual pores capacity to let the seep bubbles escape (Boles, Clark, Leifer, & Washburn, 2001). Data in the Boles, Clark, Leifer, and Washburn (2001) study only considers temporal variation in seepage rates; the spatial variability on finer scales, such as the spatial scale of the seep tents, remains largely unknown.

2.3.2 Flux of Methane

The ocean as a whole is an important source of methane to the atmosphere. However, the oceanic flux (from ocean to atmosphere) of seep derived methane is small compared to other global methane sources such as wetlands, rice production and livestock. The seeps oceanic flux is comparable to sources such as wildfires and landfills (Khalil and Ramussen cited in Clark, Washburn, Hornafius, & Luyendyk, 2000). Most of this oceanic methane flux to the atmosphere takes place in near shore waters (Clark, Washburn, Hornafius, & Luyendyk, 2000). The seeps off southern California are the largest source of dissolved methane to the local coastal waters, driving the coastal oceanic methane flux into the atmosphere. The Coal Oil Point Seeps are the largest source of the surface methane concentration in the Southern California Bight, and the study area defined for our project (Cynar & Yayanos, 1992; Clark, Washburn, Hornafius, & Luyendyk, 2000). The southern California coast is one of the most prolific areas of hydrocarbon seepage in the world with the largest documented marine seep field, the Coal Oil Point Seeps (Clark, Washburn, Hornafius, & Luyendyk, 2000). Methane produced from the seepage accounts for between 0.001 and 0.004% of total global methane production (see Section 3.9 for details).

2.4 Fate and Transport of Seep Hydrocarbons

This section focuses on the fate and transport of the seep hydrocarbons. Once the seep compounds are released into the ocean, they rapidly transform and dissolve as they travel down current. In order to estimate the impacts of tents, it is important to understand how the seep compounds change and where they go. It is also important to know where the seep hydrocarbons are going in order to estimate the ecological interaction of the seeps. The presence, flux, and distribution of seep hydrocarbons in the local waters is anomalous and is not representative of most other coastal regions in California and throughout the world (Clark, Washburn, Hornafius, & Luyendyk, 2000). Water at the bottom of the Santa Barbara Basin is more than 100-fold saturated with methane, and several studies show that the source of this methane is the seepage in the Channel (Cynar & Yayanos, 1992; Clark, Washburn, Hornafius, & Luyendyk, 2000). Studies about the sediments themselves show they are organically enriched by the seep hydrocarbons (Bauer, Montagna, Spies, Prieto & Hardin, 1988).

Most organic-rich sediment systems obtain their organic input from above in the form of sinking detritus and other organic material (Bauer, Montagna, Spies, Prieto & Hardin, 1988). For the seep sediments, the source of carbon enrichment is from underneath the sediments themselves. The constant upward flux in seep sediments is in the form of dissolved hydrocarbons, oil globules, and natural gas bubbles flowing through sea floor pores up to 0.5 cm in diameter (Bauer, Montagna, Spies, Prieto & Hardin, 1988). Sediments in the center of active seepage and those near it have several characteristics that make them unusual. TOC (total organic carbon) and other individual hydrocarbons increase with greater sediment depth as weathering and biodegradation deplete these values closer to the water sediment surface.

Eh values in the seep sediments were extremely low, which implies the complete absence of O_2 (anaerobic). Eh values represent the redox potential and the O_2 availability. This could limit the availability of seep-derived carbon enrichment to both microbial and higher consumer levels. Bauer, Montagna, Spies, Prieto and Hardin (1988) conclude that seep sediments have different geochemical cycles from the surrounding sediments and the specific mechanisms driving the anaerobic component of organic carbon cycling and uptake into the benthos are still unidentified.

Fresh oil is only present in regions of active seepage, and in all other areas only weathered oil and tar are observed. As the oil and gas released from the sediments rises through the water column and is exposed at the sea surface, the composition is modified by dissolution, evaporation, chemical oxidation, and microbial degradation (Stuermer et al., 1982). These weathered hydrocarbons either drift with the current or are deposited in the sediments nearby. However, research suggests that the seeps only have a localized effect on the marine environment (Stuermer et al., 1982). The aromatic hydrocarbons (benzene and toluene) are rapidly lost with time, mostly due to microbial degradation and evaporation of surface slicks (Stuermer et al., 1982).

2.5 Seep Ecology

Understanding the ecology of the seep sediments and how the seeps shape the local sediment ecosystem is vital in estimating impacts to the same ecosystem from seep tents installation. When the Coal Oil Point Seeps are observed from the surface as oil slicks, tar balls, oil and gas bubbles and surface film, they appear to be an extremely contaminated environment that is devoid of any life other than bacteria. However, once below the surface, divers observe a normal assemblage of plants and animals for this part of the coast (Stuermer et al., 1982). Further, there is a unique benthic community and food web structure based on bacteria that feed on the seep carbon as it degrades after coming out of the vents (Steichen, Holbrook & Osenberg, 1996). All the seeps are found in soft bottom substrate, so most of the organisms are infaunal (live in the sediments). The fish fauna is very similar to those in other soft bottom environments in Southern California (Steichen, Holbrook & Osenberg, 1996).

Organisms are exposed to seep hydrocarbons at different amounts. As mentioned earlier, variability in the seep locations and flux is substantial. Therefore, obtaining exposure rates by organisms living around the seeps is difficult. The best estimation of exposure rates has been measured for the seep area infaunal invertebrates, which burrow in the sediments around the seep areas (Straughan, 1982). Such infaunal organisms are usually exposed to weathered petroleum incorporated in the sediments, but at times may be exposed to wet petroleum buried in the sediments. Intertidal filter-feeding organisms are most likely exposed to seep gases, dissolved petroleum, or liquid petroleum. Tar at Campus (Goleta) Point forms a hard substrate suitable for settlement by a variety of marine organisms including barnacles and algae (Straughan, 1982).

Most marine species in the seep area have pelagic and motile larvae that are dispersed by currents. As a result, organisms observed in the study site are not likely to have lived within a seepage area for more than a few generations. It is difficult to define an area where organisms are exposed to chronic oil seepage over longer, evolutionary time scales. However, most organisms in the Santa Barbara channel are probably exposed to natural oil seepage at lower levels for long time scales (Straughan, 1982). Laboratory experiments on the tolerance of the mussel (*Mytilus californianus*) indicate that mussels exposed to high seepage from Coal Oil Point had a higher tolerance to local crude oil exposure than mussels from Santa Barbara (22 km east) (Straughan, 1982).

Many taxa of seep infauna are often tolerant, and well adapted to hydrocarbon exposure. Experiments comparing the colonization rates between seep and non-seep sites show that meiofaunal colonization is faster at seep sites (for copepods and nauplii, nematodes, and foraminiferans). Colonization of sediments by meiofauna is generally through passive transport, which includes suspended sediments. Given that the suspended sediments and flow levels were similar at the seep and non-seep controls, the results indicate that the increased colonization at the seep sites are due to "enhanced susceptibility to water column transport, along with behavioral differences between species" (Palmer, Montagna, Spies & Hardin, 1988). Thus, we can infer that several meiofaunal species that dwell in the seep sediments are well adapted to the seep environment and are able to disperse better than the same species in non-seep sites.

Kelp communities are diverse and biologically productive communities that include several invertebrates such as lobsters, abalone, and sea urchin populations, fish and macroplankton. No structural abnormalities or population changes were found to be related to seep exposure. Population changes of subtidal and intertidal communities in the Coal Oil Point and adjacent kelp communities are related to structural and substrate changes. Overall, studies suggest that sand movement has a greater impact on intertidal and subtidal communities than oil and tar exposure from the seeps (Straughan, 1982). Most of the ecological research has focused on sediment enrichment of the benthic fauna and there is limited information indicating the seeps sub-lethal effects on some fish species. Fishes response to seep toxicity would be species specific, depending on the feeding behavior, range in movement, and life history of the fish (Spies et al., 1996).

Available data from population, community, and ecosystem studies from the Coal Oil Point Seeps suggest a spatial and temporal pattern associated with seep exposure. Exposure to a large volume of seep hydrocarbons results initially in total or near total mortality of all organisms, followed by a stimulatory period, and finally a gradual return to 'normal' (Straughan, 1982). The time of this cycle is species specific, and the impacts are a function of exposure to petroleum. The study area is a mosaic of small units that are at different stages of this process due to the patchy distribution and variable temporal nature of the seeps. Such patchiness is shown as a possible explanation for the observed overall enrichment observed in some benthic infaunal communities (Straughan, 1982).

The natural hydrocarbon enrichment provides a large supply of organic carbon that can potentially result in higher numbers of infaunal organisms. Yet the toxic effects of the hydrocarbons, their by-products and the physical conditions of the sediments could have negative impacts on benthic organisms as well. These contrasting influences make the seeps an ideal study site for the tradeoff between organic enrichment and toxicity (Steichen, Holbrook & Osenberg, 1996). Adverse effects of the seep hydrocarbons on the benthic organisms can be due to the direct toxicity of a particular compound or chemical by-products of their biodegradation (such as sulfide). Increased sulfide levels in the seep sediments are generated by microbial activity. Secondary physical and chemical changes in the sediments resulting from the seeps, such as pH and the redox potential can also affect benthic organisms (Steichen, Holbrook & Osenberg, 1996).

The general impact of hydrocarbon seepage on the local abundance and distribution of species is defined by the tradeoff between organic enrichment and toxicity (Steichen, Holbrook & Osenberg, 1996). There is an initial area and time of almost total mortality of benthic organisms exposed to original seep products. As the seep hydrocarbons degrade into less toxic forms (by chemical and bacterial processes not well understood), some infaunal organisms (such as nematodes) are able to use them as carbon sources. Ultimately, more infaunal species are able to use the seep products with greater distance and time from initial seepage (original seep hydrocarbons). However, after a certain distance, the enrichment effect is diminished, and population's abundance and distribution returns to normal (Steichen, Holbrook & Osenberg, 1996; Straughan, 1982). As the level of fresh (un-degraded) seep hydrocarbons increase (closer to initial seepage in space and time), the sediments become more toxic to infaunal invertebrates, and more habitable to microbes. Organic enrichment is most likely due to elevated levels of microbes including *Beggiatoa* sp. as well as sulfide producers such as *Desulfovibrio* spp. (Davis & Spies, 1980).

Sediments closer to active seep fields have higher densities of the same benthic populations, while there is no dramatic difference in diversity of species. This higher abundance in seep enriched areas is most likely due to the increased bacterial biomass (Steichen, Holbrook & Osenberg, 1996). Bacterial biomass, especially for soft bottom communities is extremely important as the base of the food chain. Without the bacterial decomposition of the seep hydrocarbons, there would be much less enrichment if any at all (Steichen, Holbrook & Osenberg, 1996). Thus, the well developed bacterial and

meiofaunal communities of the Coal Oil Point Seeps transport and convert the initially toxic hydrocarbons to usable organic matter on the order of meters.

Nematodes show increased densities at about 0.5-1 meters from the seep vent, and then decrease to normal (surrounding non-seep) abundance. Nematodes seem to be the most seep tolerant/adapted infaunal organism in the sense that they can thrive in the seep carbons degraded by bacteria, which are still toxic to most other infaunal invertebrates (Steichen, Holbrook & Osenberg, 1996). Still further, about 20 meters away from the vent, there is a macrofaunal peak in abundance, where larger invertebrates reach peak abundance. Some of these interactions include food chain interactions that accumulate successive population peaks (Steichen, Holbrook & Osenberg, 1996; Straughan, 1982).

Taken together, past studies indicate a halo effect: infaunal densities are extremely low in the most contaminated active seep vents (due to toxicity), reach a maximum at 'clean' sites within the seepage area (due to enrichment), and are lower (same as non-seep abundances) again at distant sites (50-1000 m from the seeps) where there is no enrichment (Steichen, Holbrook & Osenberg, 1996).

Effects of the Coal Oil Point Seep hydrocarbons on the ecology of the water column are not fully documented. There is limited research that looks at the species-specific sub-lethal biological effects of the seeps on fish (Spies et al., 1996). Subtle biological effects of chronic hydrocarbon exposure have been studied for the last 20 years with regard to anthropogenic petroleum extraction, transportation, and spills in the oceans (Spies et al., 1996). Most of these studies are in coastal environments and there are multiple contaminant sources, exposing fish to a mixture of pollutants. The Coal Oil Point Seeps provide a natural laboratory in which to study and isolate the effects of long-term exposure of fish to the seep hydrocarbons (Spies et al., 1996). Results of the limited experiments on the sub-lethal effects of fish show that the response is species specific, with lesions in the liver and gills as the common effect. Impact of the seep hydrocarbons varies depending on the feeding range, movement and life history of each fish (Spies et al., 1996). Further, it is not known if the negative effects indicated by the experiments are offset by the potential for more food in the locally enriched seep sediments.

2.6 Potential Impacts of the Tents on the Seep Flux

Given what is known about the seep flux, it is possible to estimate the impacts of seep tents on the flux of hydrocarbons released into the ocean and atmosphere. Capping the seeps would reduce the amount of hydrocarbons (including ROGs) that is released to the ocean, and atmosphere.

We assume that ROGs emitted from the seeps dissolve at the same rate as methane, so half the ROGs dissolve in the water column. However, not all the ROGs are emitted directly from the seep bubbles. Some are formed when the oil slicks are exposed to sunlight and air as well. Approximately 20% of the total emitted ROGs come from the tar slicks, and the remaining 80% comes directly from the bubbles popping at the surface

(Luyendyk, 2001). Capping the seeps would therefore only impact the ROGs from the bubbles and not the tar slicks.

The exact relationship between the seep hydrocarbons and ROGs is not known. Since the hydrocarbons in the water column ultimately come from the seeps, we assume a linear relationship between the seep bubbles captured and hydrocarbons that reach the atmosphere (Luyendyk, 2001). The tents are assumed to capture both sources of ROGs because the tar is formed when the seep bubbles pop and the liquid petroleum film at the surface of the bubbles condenses to form the tar. Capturing the bubbles before they pop captures both the gas inside them as well as the oil film around them (Quigley, 1997). However, the seep tents will not collect the oil and tar associated with the bubbles, and will probably release them back into the ocean on site.

The seep tents' weight on the sea floor may change the location of seep vents. Seep locations shifted outside the original skirts of the two tents installed by ARCO, and to capture the shifting seeps, additional 450 m^2 skirts were added in 1986 (Boles, Clark, Leifer, & Washburn, 2001). It is not known if the shift was due to the load of the tents (each weighing 2.27 x 10^5 kg) or if it was natural variation or a combination of the two. Any additional seep tents will probably be made of lighter material than the steel and concrete ARCO tents. Thus, they will not exert much pressure on the seep sediments. Since the reasons behind the shift in seepage under the ARCO tents are not clear, the spatial variation in seepage should still be of concern for a possible seeps tents project.

2.7 Potential Impacts of Seep Tents on Marine Environment

Given the seep ecology, this section explores the potential impacts from adding more seep tents and associated pipelines to the ocean floor within the study area. Marine impacts will result from the installation (both tents and pipeline), operation, maintenance, movement, possible leakages, and abandonment of the seep tents in the study site. Impacts on the water quality of installing seep tents will likely be non-detectable because of the nature of the dissolved hydrocarbons. This section focuses primarily on marine ecological impacts.

The following impacts are estimated from various sources including EIS/EIRs from ARCO's planned oil platform installations, expert opinions, and other sources. We consider the impact of the tents as well as the associated pipeline infrastructure. Once the exact location of the seep tents, the area of coverage and the pipeline distance and dimensions are quantified, it will be possible to quantify the impacts more accurately. However, this is outside the scope of this project, and will need additional research to be clear. For now, more qualitative descriptions and predicted trends in the nearshore marine ecology due to the possible installation of additional seep tents are presented. A complete EIS/EIR as required by law will quantify specific impacts related to such a project.

Physical disturbance of the bottom sediments directly associated with the emplacement of the seep tents will cover an approximate area of 900 m^2 per tent. During installation there will be extensive short-term local disturbance to the water column and sediments. Fully

constructing the tents onshore will reduce the impacts resulting from installation. Since the shape, size and anchoring specifics are not known at this time, it is hard to estimate the impacts the tents will have on the sea floor during installation. However, if the tents are designed to be mobile, during each location change, there will be repeated impacts on the sediments.

Depending on the bottom habitat type of the exact location of tent and pipeline installation, the impacts will differ. During the sub surface pipeline installation, both the anchors and the lay barge will disturb the bottom substrate, and increase turbidity. Mobile species would repopulate the temporarily impacted areas during installation. Similarly, sedentary organisms would also colonize the temporarily impacted areas in less than five years at most (ARCO, 1987). Generally, both temporary and permanent ecological impacts on hard bottom substrates are considered to be greater than impacts on soft bottom substrates. This is because hard bottom habitats support ecosystems with higher biomass, and more trophic interactions, so it takes longer time to recover for some of the larger organisms (ARCO, 1987). Approximately 70% of the bottom habitat within the Channel is soft bottom, opposed to hard bottom (rocky) (Channel Islands National Marine Sanctuary [CINMS], 2000). This evaluation indicates that the seeps are on soft bottom sediments. Short term localized impacts from tent installation to these habitats will not be permanent or have secondary effects throughout the ecosystems.

Habitat covered and impacted by the installation and laying of pipelines will be larger than the habitat covered and impacted by the seep tents. Therefore, the impacts from the pipeline installation can be expected to be greater than the seep tents installation. The pipeline installation will affect the surf and intertidal zones as the pipeline connects to an onshore facility. Impacts on the surf and intertidal communities will depend on the exact location and nature of the pipes landfall. Disturbance to the rocky bottom intertidal and surfgrass (*Zostera* sp.) meadows at the landfall site will be of special concern.

Surfgrass and rocky bottom areas are known to provide extremely diverse habitat, nursery areas for juvenile fishes and invertebrates, and support high species diversity and biomass compared to similar intertidal sandy beaches (CINMS, 2000). Similarly, kelp beds are extremely sensitive habitats that support high biodiversity, and they are critical to the near shore ecosystem integrity (CINMS, 2000). The highest species diversity off Southern California waters is associated with kelp beds (CINMS, 2000). The California Coastal Act considers kelp beds environmentally sensitive habitat.

Impacts of pipeline construction on subtidal soft bottom habitats will be resulting from physical lying of pipeline, the setting of lay barge anchors, and the drag of the anchor cable. Soft bottom habitats recover rapidly from such disturbance, and the shallower (less than 100 ft deep) soft bottom habitats are expected to recover in less than three years (ARCO, 1987). There is not sufficient data to predict the recovery time of deeper soft sediments although less than five years is a good estimate (ARCO, 1987). Because of the large area that will be disturbed by pipeline installation the impacts should be considered significant. However, minimizing the linear distance of pipeline and thus the area

affected can reduce this impact. Sand dollar beds are important subtidal communities to monitor, which do not necessarily recover from disturbances.

Seep tent installation will primarily result in localized short-term sediment disturbance, which will cause a pulse of turbidity plumes. Depending on how close the tents will be to nearby kelp beds, there will be a temporary increase in the turbidity at or near the kelp beds. Increased turbidity has been shown to negatively impact kelp survival and reproduction (ARCO, 1987). Because of the key role kelp beds play in nearshore marine ecosystems, the impacts from pipeline installation can be high, even at a local and regional scale. Even though the physical disturbance (i.e. turbidity plumes) caused by pipeline installation is expected to be localized and temporary, the overall impact to the kelp habitat can be long-term. This is because kelp recruitment occurs in relatively rare recruitment windows. If a turbidity plume were to sweep into a kelp bed during one of the rare recruiting periods, this could prevent successful establishment of young kelp. Thus, even a brief and temporary pulse of turbidity caused by the pipeline installation can impact the kelp dynamics over the long term, without affecting the survival of the individual adult kelp (ARCO, 1987). However, the exact location, duration, and magnitude of the disturbance will determine if there will be a significant measurable impact on the kelp beds.

Plankton may suffer some short term, localized stress from the increased turbidity. Due to the transient nature of marine plankton, impacts on phytoplankton and zooplankton from installation are expected to be insignificant (ARCO, 1987). Impacts on pelagic fish will at most be temporary avoidance of the tent and pipe installation sites. Given the extent of soft sediment habitat and the relatively small area of the tents, bottom dwelling fish, which prey on the infaunal organisms of the sediments, are not likely to be impacted from the installation of the tents over the long term. Because of the off site construction, and offshore installation, possible impacts from the seep tents on the nearby intertidal communities are assumed to be non-existent.

Overall, in the long term, there will probably be no detectable effects on the local ecology of the study area, unless there are significant impacts on nearby kelp beds. The detectable marine impacts will most likely be due to construction and installation of the tents and the pipeline. If the tents are constructed with mobility, so that they can be easily transported to other seeps (within the same Coal Oil Point seepage area), then similar short-term impacts will be to be repeated. Such impacts will most likely be temporary and directly proportional to the magnitude and duration of the activity.

The principal impacts associated with seep tent installation and pipeline construction at the marine ecosystem level are due to the potential disturbance on the kelp communities. Permanent (or long term) damage of the intertidal surfgrass communities by the landfall connection of the pipeline can also have negative ecosystem level impacts. Because the disturbances from the seep tents and pipelines installation will be extremely localized and temporary, as long as the placement of tents and routing of the pipeline minimize the effects to the kelp and surfgrass beds, the project is estimated to have little long-term significant impacts on the nearshore marine ecosystem of the site. However, depending

on how much sensitive habitat (kelp and surfgrass) is affected, the impacts could be significant.

We assume that the oil and tar collected in the tents will be disposed back into the water column, so any measurable effect of reduced tar and oil in the water column is negligible. However, it is important to note that, even if the oil were collected and disposed/processed on land (removed from the ocean) it is unlikely that there would be any detectable biological impacts or changes in beach tar (CINMS, 2000). This is because sand movement, erosion, and accretion dominate beach ecosystem dynamics (ARCO, 1987). In other words, for small amounts of oil and tar exposure (such as exposure associated with the seeps), the impact of sand movement dominates the impact of oil and tar to the intertidal communities.

If the pipeline will not be connected to land, and instead connected to a nearby offshore oil platform such as Holly, the potentially significant ecological impacts from the pipeline will be greatly reduced. In such a case, there would be no landfall of the pipeline so the intertidal and ecologically valuable surfgrass habitats would be undisturbed. Similarly, kelp beds do not grow deeper than 30 meters of water, so the pipeline connecting the tents (at depths of 40-60m) to platform Holly would not come near any sensitive habitat (CINMS, 2000). Thus, if the gas collected from the seep tents is routed initially to the offshore oil platforms, the nearshore marine impacts will be reduced. Likewise, the gas collected can be routed to a processing facility using another existing nearby pipeline. An important point is that the impacts are directly proportional to the extent and area covered and disturbed by the pipeline. So fewer pipelines mean less potential impact on nearshore marine ecosystems.

2.8 Conclusion

The Coal Oil Point seeps present a unique assemblage of soft bottom infaunal communities where the base of the food chain are microbes that are able to decompose the seep carbon. Once the initially toxic seep carbon is decomposed, it becomes available for other organisms' uptake. The microbes are a prime food source for several infaunal invertebrates, which themselves are food for larger organisms. Thus, the toxic appearance of the seeps does not prevent a unique and productive marine ecosystem to prevail.

Compared to the more sensitive and species rich habitats such as rocky reefs, kelp beds, and surfgrass beds of the Southern California coast, the seeps are found on soft bottom sediments. Soft bottom areas are usually less sensitive to permanent damage. However, there can still be significant negative impacts of installing seep tents to the marine ecology. In order to have the minimal impact on the marine environment, the pipeline infrastructure should avoid damaging nearby sensitive habitats.

Note that this is a preliminary study about the seep tents impacts. If in the future additional tents will be installed, and the exact location is known, a more detailed,

comprehensive, and quantitative EIS/EIR on their marine impacts should be undertaken, as required by law.

Chapter 3: The Effects of Marine Hydrocarbon Seep Capture on Air Quality and Climate

3.1 Introduction

The hydrocarbon emissions from the Coal Oil Point Seeps contribute to the formation of ozone in Santa Barbara County. In addition, 87% of the seepage emissions are methane, which is a greenhouse gas that causes global warming. Using an ozone production model, the air quality and climate section of this report attempts to quantify the amount of ozone that is produced by the seep area and the amount of ozone emissions that may be reduced by the installation of seep tents. This section also estimates the fraction of global methane that is emitted from the seep tents. This information will be useful in determining the cost and benefits of reducing the seep emissions through tenting.

In the stratosphere, or middle atmosphere, ozone occurs naturally and protects people and most biota from the sun's damaging ultraviolet radiation. However, in the troposphere, or lower atmosphere, ozone is the result of natural and anthropogenic pollution and is known to be harmful to human health and the environment. Tropospheric, or ground level ozone, is the primary ingredient of photochemical smog, which is an important and damaging type of air pollution. (EPA-5, 2001).

Tropospheric ozone is formed when two general types of gaseous compounds interact with ample sunlight. These two compounds are generally referred to as reactive organic gases or ROGs[*], which have other synonymous names (also known as volatile organic compounds or VOCs*, and reactive organic compounds or ROCs*), and nitrogen oxides or NO_x. The Coal Oil Point Seeps release considerable amounts of methane and ROGs. In the presence of sunlight these ROGs interact with the NO_x gases. The overwhelming source of NO_x gases in Santa Barbara County (and globally) is the internal combustion engine, which is found in automobiles, trucks, ships, and other fossil fuel combustion. Given ample sunlight, ozone formation in Santa Barbara County is a function of the interaction between ROGs (from anthropogenic and natural sources) such as the seeps, and NO_x (from primarily anthropogenic sources). A more detailed explanation is provided in Section 3.5.

3.2 Seep Gas Composition and Speciation

The seep gas and gas volatized from the floating seep oil is composed of several different gases, or species. The seep gas is composed of non-methane hydrocarbons, methane, and air toxics. Non-methane hydrocarbons contribute most significantly to the production of

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[*] Note that there are some differences within all the different organic compound classifications, yet ROG is generally the most common term used. So for the sake of simplicity we refer to all seep originated VOC and ROC gases under the more comprehensive group of ROGs.

ozone, methane is considered a greenhouse gas, and air toxics are of concern due to their carcinogenic risk. Air toxics are a type of non-methane hydrocarbon.

The species in the seep gas include nitrogen, oxygen, carbon dioxide, methane, ethane, propane, iso-butane, n-Butane, iso-pentane, n-Pentane, hexane, and hydrogen sulfide (see Table 2). These hydrocarbon emissions, including methane, are precursors to the formation of tropospheric ozone.

Table 2. Seep Emission Speciation and Mole Fraction. Source: (Clark, 2001)

Species	mole %
Methane	87.49
Ethane	5.09
Propane	3.07
Carbon Dioxide	1.3
N-Butane	0.87
Nitrogen	0.79
Iso-Butane	0.43
Hexane+	0.34
Iso-Pentane	0.24
N-Pentane	0.23
Oxygen	0.14
Benzene	0.00938
Toluene	0.00313
Hydrogen sulfide	0.00246
Xylene	0.00101

The estimates of total seep gas flux from the ocean surface vary greatly. For this study, we use an estimate of $10^5 \, m^3$ per day for the total seep gas flux emitted from the ocean surface (Clark, 2001). Refer to the background section for a more detailed discussion on the various estimates of the seep flux from the Coal Oil Point seep field.

3.3 Health and Environmental Effects

Exposure to background (ambient) ozone concentrations, even at relatively low levels and for brief periods of time, is known to cause respiratory symptoms including reduction in lung function, chest pain, and cough. Repeated exposure to ozone can increase vulnerability to respiratory infection and lung inflammation, and can aggravate preexisting respiratory diseases such as asthma, especially in children. Ozone may also worsen bronchitis, heart disease, emphysema, and asthma, reduce lung capacity, and may cause permanent lung damage (EPA-5, 2001; EPA-3, 2001). Because ozone pollution forms in warm weather it often affects people who spend time outdoors including children, the elderly, outdoor workers, and people exercising. Ozone can also cause healthy people to experience respiratory difficulty (EPA-3, 2001). See Section 5.4 regarding the monetary valuation of these health conditions.

Ground-level ozone also damages plant life causing an estimated $500 million in reduced United States crop production each year by interfering with the ability of plants to produce and store food, making them more susceptible to disease, insects, other pollutants, and harsh weather (EPA-3, 2001). Further, ground level ozone damages the foliage of trees and other plants, ruining the landscape of cities, national parks and forests, and recreation areas (EPA-3, 2001).

Such adverse health effects associated with the inhalation of ozone are the basis for the National Ambient Air Quality Standards (NAAQS). Ozone is one of the six criteria pollutants determined by the EPA Office of Air Quality Planning and Standards (OAQPS). The criteria pollutants are ozone, carbon monoxide, nitrogen dioxide, lead, particulate matter 10 micrometers in diameter or less, and sulfur dioxide (EPA-4, 2001). The federal primary and secondary 1-hour average for ozone is 0.12 ppm (235 $\mu g/m^3$ or 120 ppb) (EPA-4, 2001). An 8-hour average of 0.08 ppm (157 $\mu g/m3$ or 80ppb) was proposed by the EPA in 1997, but was blocked by a 1999 federal court ruling (EPA-4, 2001). The federal standard can be exceeded only 1 time per year in order to maintain attainment, whereas the state standard is not to be exceeded (California Air Resources Board [CARB-1], 2001).

3.4 Monitoring Ozone

The Clean Air Act (CAA) requires the EPA to set NAAQS for pollutants considered harmful to public health and the environment. The CAA established two types of NAAQS, primary standards and secondary standards. Primary standards are health based standards that set limits to protect public health including the health of "sensitive" populations such as asthmatics, children, and the elderly, while secondary standards set limits to protect public welfare such as protection against decreased visibility, damage to animals, crops, vegetation, and buildings (EPA-4, 2001).

The Clean Air Act Amendments of 1990 require EPA, states, and cities to implement programs to further reduce emissions of ozone precursors (ROGs and NO_x) from sources such as cars, fuels, industrial facilities, power plants, and consumer/commercial products (EPA-4, 2001). The Santa Barbara County Air Pollution Control District Emissions Inventories and Clean Air Plans are part of this effort to reduce ground level ozone.

The Santa Barbara County Air Pollution Control District (APCD) monitors several air pollutants in compliance with the California Air Resources Board as outlined in the California Clean Air Plan (SBCAPCD-2, 2001). Ozone, Reactive Organic Gases (ROGs), Particulate Matter, and Air Toxics levels are monitored by the APCD in order to reduce emissions over time from different sources. Every three years the APCD is required under the Clean Air Act to publish a Clean Air Plan that quantifies emissions and their respective sources.

The "smog season" in Southern California is from April through October, during the months with the most sunlight hours in the year and thus the most sunshine and ultraviolet rays (SBCAPCD-3, 2001). Ozone levels in Santa Barbara are also influenced

by constituents that migrate into the Santa Barbara Air Basin from offshore and from air basins to the south including the notoriously smoggy Los Angeles Air Basin (SBCAPCD-3, 2001). Since air quality monitoring began in 1971, the year 2000 is the first year that Santa Barbara County did not exceed the Federal 1-hour ozone standard and is thus the best ozone year on record (SBCAPCD-3, 2001).

Ozone levels vary throughout the County at any given time. Although stagnant air conditions can cause exceedances more frequently in some canyon areas, the Federal and State ozone exceedance days in Santa Barbara have declined over the years. Figure 3 shows decline in the number of exceedance days over the last 10 years.
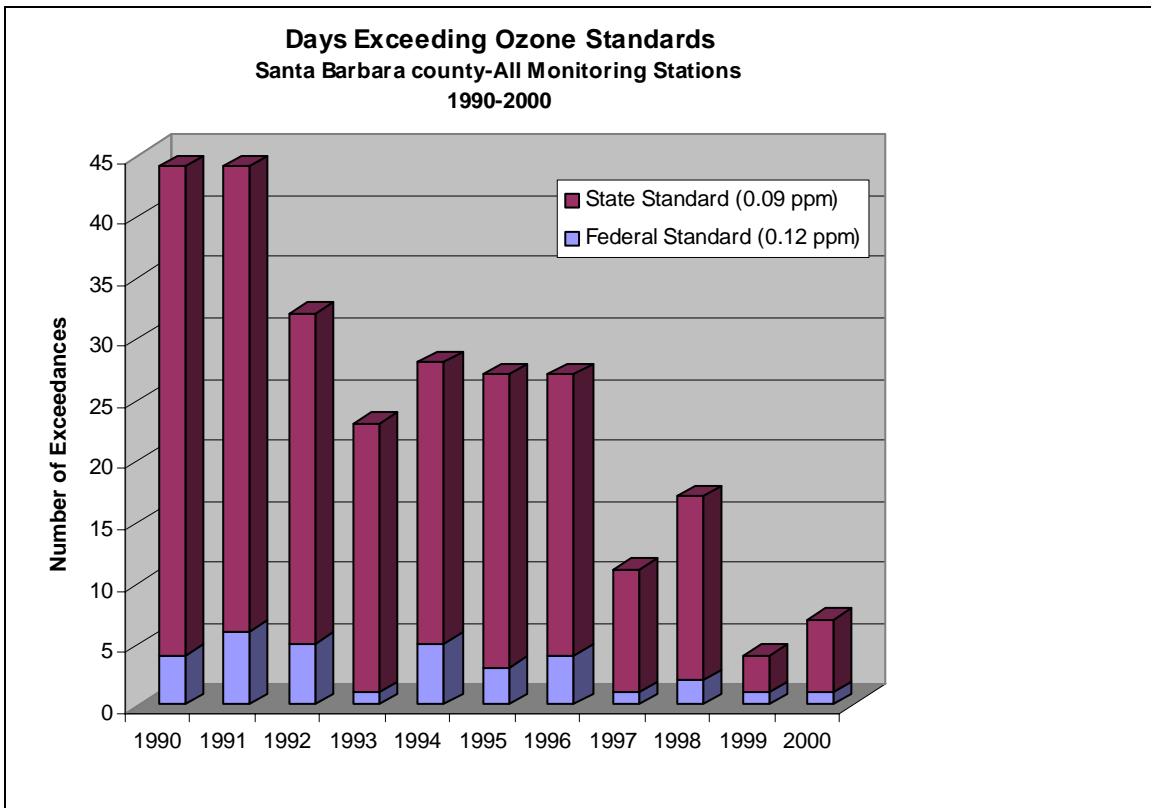
Figure 3. Ozone Exceedance Days in Santa Barbara County (SBCAPCD-4, 2002)

3.5 Urban Ozone Production Processes

In the presence of the sun's ultraviolet rays, ozone is formed from the reactions between Reactive organic gases (ROGs) and Nitrogen oxides (NO_x). Figure 4 and 5 below summarize the reactions that take place. Since the main source of NO_x emissions is fossil fuel burning activities, ground level ozone is generally a problem in sunny urban areas.
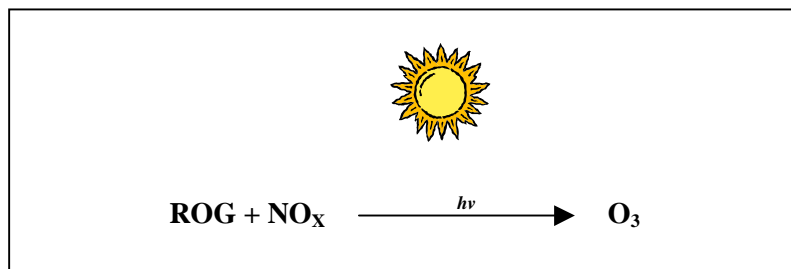
Figure 4. Reactive organic gases and nitrogen oxides react in the presence of sunlight to produce ozone.

Reactions
$O_3 + hv \rightarrow O_2 + O(^1D)$
$O(^1D) + M \rightarrow O + M$
$H_2O + O(^1D) \rightarrow 2OH$
$CO + OH \rightarrow CO2 + H$
$H + O2 + M \rightarrow HO2 + M$
$RH + OH \rightarrow RO_2 + H2O$
$RO_2 + NO \rightarrow RO + NO_2$
$RO + O_2 \rightarrow R'CHO + HO_2$
$HO_2 + NO \rightarrow OH + NO_2$
$RH + 4O_2 \rightarrow R'CHO + 2O_3 + H_2O$ Net

Figure 5: Partial list of urban ozone production reactions. Source: Jacobs, 1999.

In Figure 5, the reactive organic gases are noted with an "R" group in their chemical formula. Each gas has a different capacity to produce ozone by altering the number of times that the above reaction chain can take place. The capacity for each gas to create ozone is termed its "reactivity." Gases with a high relative reactivity cause an ozone forming reaction chain to occur more often (thus producing more ozone) than gases with a low relative reactivity.

3.6 Ozone Production Model

An ozone production model is used in this report to estimate the ground-level ozone produced in Santa Barbara County from various sources. In this model, the incremental reactivity of each hydrocarbon gas species determines the amount of ozone produced (Seinfeld & Pandis, 1998). For example, using this model, one mole of propene creates about 374 times as much ozone as one mole of methane. Thus, propene has a higher incremental reactivity and is much more reactive than methane. The reactivity of hydrocarbons depends on the number of carbons and the structure of the molecule. This model calculates ozone production as follows:

$$\text{moles of ozone} = (\text{moles of carbon}) \times (\text{incremental reactivity})$$

For each species of gas used in the model (Table 3) moles of carbon per year is estimated based on the chemical formula and atomic weight.

Table 3. Table of reactive gases used in ozone production model. Source: (Seinfeld & Pandis, 1998).

Compound	Incremental Reactivity (mol O_3/molC)	Chemical formula	Atomic weight	# C
Carbon monoxide	0.019	CO	28.010	1
Methane	0.003	CH_4	16.000	1
Ethane	0.030	C_2H_6	30.0694	2
Propane	0.069	C_3H_8	44.0962	3
n-butane	0.124	C_4H_{10}	58.123	4
n-octane	0.081	C_8H_{18}	114.230	5
Ethene	0.770	C_2H_4	28.054	2
Propene	0.820	C_3H_6	42.080	3
Trans-2-Butene	0.810	C_4H_8	56.107	4
Benzene	0.023	C_6H_6	78.1134	6
Toluene	0.106	C_7H_8	92.1402	7
m-Xylene	0.500	C_8H_{10}	106.167	8
Formaldehyde	1.260	CH_2O	30.026	1
Acetaldehyde	0.700	C_2H_4O	44.053	2
Benzaldehyde	-0.290	C_7H_6O	106.124	7
Acetone	0.055	C_3H_6O	58.080	3
Methanol	0.147	CH_4O	32.042	1
Ethanol	0.190	C_2H_6O	46.069	2
Isoprene	0.700	C_5H_8	68.118	5
a-Pinene	0.210	$C_{10}H_{16}$	136.236	10
Urban mix	0.280	$\sim C_2H_6$	~30	~2

The speciation of natural source emissions in Santa Barbara County is estimated using the 1999 ROG Emissions Inventory from the 2001 Clean Air Plan ROG emissions inventory data and the Draft California Emission Inventory Development and Reporting System (CEIDARS) ARB Organic Gas Speciation Profiles (9/12/2001) (Fredrickson, 2001), and the seep gas flux and speciation assumptions from Table 3. This specific model assumes that the modeled region is ROG-limited as opposed to NOx-limited, which is most likely an over assumption of seep contribution to ozone production (see Section 3.8).

The speciation of all natural sources and respective mass per year of each species is entered into the model from data provided by the APCD. The total mass per year of all remaining non-natural sources (Stationary, Area-wide, and Mobile Sources) is entered into the general "Urban mix" portion of Table 2, which assumes a reactivity of 0.28. According to the APCD, Stationary Sources include individual facilities and aggregated point sources, Area-Wide Sources include geographically dispersed area sources, Mobile

Sources include both on-road vehicles and off-road sources, and Natural Sources are non-anthropogenic sources (SBCAPCD-2, 2001). As shown in Table 4, the natural biogenic sources contribute about 51% of the ROGs in Santa Barbara County (SBCAPCD-2, 2001). Biogenic sources include natural and agricultural vegetation. Thus, according to this model, ROGs (mainly isoprene) emitted from vegetation produces about half the ozone in the county airshed in a fully ROG-limited regime.

Table 4. **Santa Barbara County 1999 ROG Emissions. Source: (SBCAPCD-2, 2001)**

Source	ROG Emissions	% of Total ROG Emissions
Stationary Sources	3059	7
Area-Wide Sources	3271	7
Mobile Sources	9031	20
Natural Sources	28,930	65
Biogenic Sources	22,532	51
Geogenic Sources (Seeps)	6,042	14
Wildfires	356	1
Windblown Dust	0	0
Total ROG Emissions	44,291	100

Based on the above assumptions, Table 5 lists the ozone production model results of ozone produced by each source and the percent of total ozone produced per year. These estimates assume that no tents are installed.

Table 5. **Model output: Santa Barbara County annual ozone production**

	Tons/ year	mol C / year	mol O_3 / year (based on IR)	Relative reactivity mol O_3/ mol C	% of total SB ozone per year
Seeps gas total (natural)	29068	1.73E+09	3.06E+07	0.018	4.82
Biogenics total (natural)	43621	2.60E+09	3.27E+08	0.126	51.43
Wildfire total (natural)	562	3.51E+07	1.79E+07	0.509	2.81
Urban mix (Total SB - natural)	15361	9.29E+08	2.60E+08	0.280	40.95
TOTAL SB (natural +Urban)	88612	5.30E+09	6.35E+08	0.120	100.00

Although the geogenic seeps produce about 14% of the ROGs in Santa Barbara County, they produce less than 5% of the ozone according to the ozone production model. This is a result of the large volume of methane in the seep gas, which reacts very slowly with NOx, thus producing less ozone in a nonlinear fashion.

3.7 Seep Tent Gas Capture

Installing seep tents on the ocean floor to capture seep gas could reduce the amount of emitted reactive organic gases thus reducing ozone production in Santa Barbara County. Details of seep gas capture are presented in Chapter 5.

3.8 NO$_X$ Emissions and Ozone Production

In order for us to determine the impact of the project on air quality, it is important to understand the possible atmospheric conditions that create ozone. The amount of ozone produced in Santa Barbara is a function of the climatic conditions, the levels of ROGs and NOx, and the large spatial and temporal variability of these components. We consider three different atmospheric regimes. The first is an ROG-limited regime in which ozone production is regulated by ROGs. In this environment, capturing seep ROGs will reduce the amount of ozone produced. The second is a NOx-limited regime in which NOx regulates ozone production. In this environment, ozone is not produced by additional ROGs. Therefore, ROGs released from the seeps will not contribute to ozone formation. Finally, the third regime is co-limited, where both NOx and ROGs regulate ozone production. Thus capturing seep ROGs will have some impact on ozone reduction.

Figure 5 shows a sample of the important reactions involved in ozone-producing photochemistry. There are actually hundreds of reactions that are relevant to urban air quality, and many more that are unknown (Seinfeld & Pandis, 1998). Generally speaking, in the presence of NOx, the oxidation of organic species leads to the formation of ozone. However, there are also reactions between different radical chemical species, which occur under extremely polluted conditions that cause a non-linear relationship between emissions of reactive organic gases and nitrogen oxides. Describing all of these reactions is beyond the scope of this study. However, one can simplify these complicated reactions (Jacob, 2000) and find that there are generally three regimes: NOx-limited, ROG-limited, and co-limited. In a NOx limited regime, ozone production is limited by NOx, and thus the amount of ozone is most constrained by the NOx emissions. The National Research Council report, *Rethinking the Ozone Problem in Regional and Urban Pollution*, indicates that many of the large US cities are in NOx-limited regimes (1991). In a ROG limited regime, the ozone production is limited by emissions of ROG, while in the co-limited regime, both compounds are similarly limiting. Thus, if we are in a NOx-limited regime in Santa Barbara, ozone production will not be affected by the amount of ROG emitted.
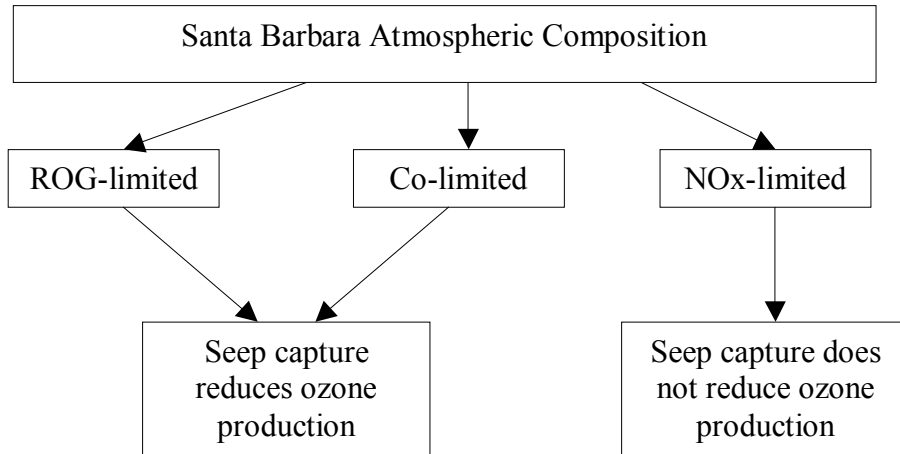
Figure 6. **Effects of seep gas capture in possible air quality regimes.**

In a NO$_x$-limited system, incrementally changing the amount of ROG emissions (by tenting the seeps) will not change the level of ozone production. However, in an ROG-limited system, changing the ROG emissions will change the level of ozone production. Thus, the type of regime present in Santa Barbara County is relevant as to whether or not capture of seep gas emissions will actually reduce ozone production. Figure 6 shows the effect of the atmospheric regime to the possibility of seep emission capture being able to reduce ozone. If the Santa Barbara regime is ROG-limited or co-limited, the capture of ROGs will reduce ozone. However, it is possible that Santa Barbara County air basin is either in a NOx-limited or co-limited regime.

To determine which regime Santa Barbara County is in, we compare the ratio of hydrocarbon emissions to NOx emissions. The Table 6 estimates the ratio of atoms of C per square centimeter to molecules of NOx per square centimeter in the County from the 1999 Emissions Inventory. We assume the area of Santa Barbara County to be 1,752,620 acres (7.09E+13 square centimeters) (California Environmental Resources Evaluation System [CERES], 2002). The ratio computed is 3.16 to 1. By plotting the ratio in Figure 7, we find that Santa Barbara is in a NOx-limited regime. It should be noted that the moles of Carbon are underestimated because not all sources of carbon (i.e. methane and ethane) are included in the Emissions Inventory. If all sources of carbon are included, the ratio of C:NOx is greater than 3.16 to 1 and farther into the NOx-limited regime. For the purposes of the economic model, we assume a co-limited environment and estimate the ozone production at 50% of the value simulated in the ozone production model with ROG-limitation.

Table 6. **Ratio of carbon to NOx.**

tons ROG per year	grams ROG per year	ROG (grams/mol)	mol C per year	10^{11} atoms of carbon	10^{11} atoms of carbon per cm^2	
47,800	4.34E+10	30	2.89E+09	1.74E+22	2.45E+08	**Ratio C:NOx**
tons NOx per year	grams NOx per year	NOx (grams/mol)	mol NOx per year	10^{11} molecules of NOx	10^{11} molecules of NOx per cm^2	**3.16:1**
30,298	2.75E+10	30	9.16E+08	5.52E+21	7.78E+07	
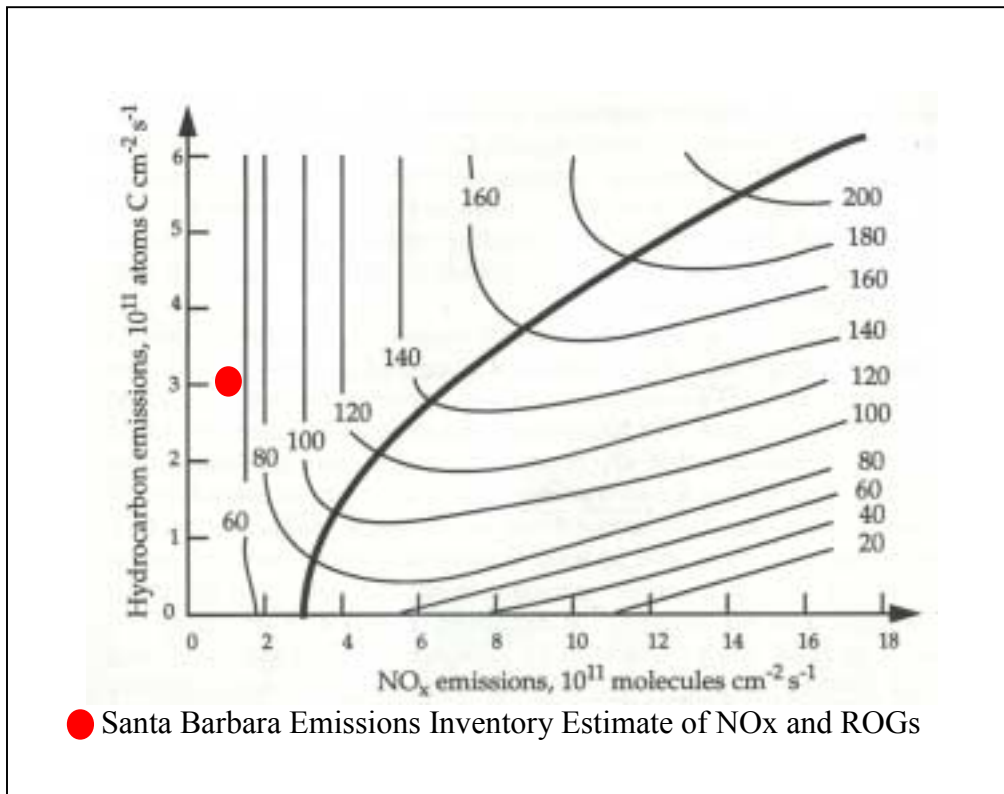
Figure 7. Estimate of Santa Barbara County ROG to NOx ratio (3.16:1). Source: Jacob, 1999

Although Figure 5 suggests that Santa Barbara County is in a NOx-limited regime, this graph does not take the airshed spatial and temporal variation into account. As mentioned earlier, the ozone production model used to predict ozone production assumes that Santa Barbara is in an ROG-limited regime environment, modified to estimate a co-limited regime for the most-likely scenario. Therefore, all estimates of ozone production may be overestimated if Santa Barbara County is in fact NO_x or co-limited.

3.9 Methane

The seeps speciation used in the ozone production model is the most comprehensive speciation available. However, this speciation represents gases captured from the ocean floor, as it is an average of the different gas volumes from data that has been collected over time from the ARCO seep tents. As shown in Table 2, the seep gas at the ocean floor is assumed to be 87% methane. In reality, part of the methane dissolves in the water column as it travels to the ocean surface. It is estimated that the actual quantity of methane emitted from the ocean water surface from the seeps is 50 to 60% of the total flux from the ocean floor of 10^5 m^3 of gas per day. Only the methane that is emitted from the water surface will influence the amount of ozone produced in Santa Barbara and the global methane production.

In order to determine the extent that ozone production is effected by a difference in volume of methane escaping from the water surface, the ozone production model is simulated with methane volumes of 50%, 60% and 87%. It should be noted that this simulation does not change the volumes of non-methane hydrocarbons. It assumes that these species do not dissolve in the water column and that they have the same concentration at the ocean floor as at the water surface. As seen in Table 6, comparing the seep gas speciation of 87% methane with seep gas methane speciation of 60% and 50% shows that the total hydrocarbon gas decreases 7313 tons per year with a 3.4% decrease in ozone production with 60% methane and 9973 tons per year with a 4.6% decrease in ozone production with 50% methane. Despite the fact that methane has a low reactivity, when methane emissions are reduced, ozone production is also reduced. Although a seep gas surface speciation with 50% methane composition is the most likely estimate for the actual methane emissions from the water surface, the sea floor seep speciation is used in the ozone production model, as it is the most comprehensive speciation available. In addition, it provides an upper limit as to the amount of methane that could potentially be produced.

Table 7. **Seep gas emissions from ozone production model with different methane volumes.**

Seep gas speciation	Tons/year	Moles C/year	Moles O₃/year
87% methane	30370	1732208940	30597909
60% methane	23057	1317587040	29561354
50% methane	20397	1166760593	29184288

The total flux of methane is assumed to be 0.5 x 10^5 m^3 per day (Clark, 2002). This equates to about 1.21 x 10^{10} g of methane per year emitted from the seeps. The global budget of methane emissions is 285 x 10^{12} to 840 x 10^{12} g/year (Jacob, 1999) with natural sources contributing about 180 x 10^{12} to 380 x 10^{12} g/year (Institute on Climate and Planets, 2001). As shown in Table 8, it is estimated that the Coal Oil Point Seeps contribute 0.001 to 0.004% of the total global methane emitted to the atmosphere each year.

Table 8. **Global methane and seep flux fraction estimates**

Global methane budget estimate	Grams/year	% contribution of seep methane to global methane budget
Conservative	2.85E+14	0.004
High	8.4E+14	0.001

According to the EPA, methane is considered a greenhouse gas and traps over 21 times more heat per molecule than carbon dioxide (EPA-2, 2001). Thus, it has a higher global warming potential (GWP).
Table 9 shows that GWP of methane is higher in the short-term than in the long-term.

Table 9. Global warming potential of methane compared to carbon dioxide. Source: Jacob, 1999

Gas	Lifetime, years	GWP over integration time		
		20 years	100 years	500 years
CO_2	~100	1	1	1
CH_4	10	62	25	8

3.10 Conclusions and Recommendations

Seep gas is primarily composed of methane, a less reactive gas in the ozone production model. According to the ozone production model used in this analysis, the seep gas is about four times less reactive than anthropogenic gas (Urban Mix). Thus, as a whole, the seeps contribute less significantly to ozone production than do urban anthropogenic sources. In addition, the seep gas methane is a small fraction of global methane production and thus capturing it may have a very small effect in reducing the effects of global warming.

The amount of ozone produced will be a factor of the regime. In a NOx-limited regime, reducing seep gas emissions via seep tent capture will not effect ozone production. In a co-limited regime, reducing seep gas will reduce ozone production somewhat. Finally, the greatest reduction in ozone production will come from reducing seep gas in an ROG-limited regime. Therefore, it is recommended that the seep gas at the surface of the ocean be more accurately speciated to determine the types and amounts of each gas emitted to the atmosphere. Ultimately, the air quality regime within the Santa Barbara Area should be more accurately quantified.

Several uncertainties remain regarding ozone production in Santa Barbara County including the determination of whether or not the area is in a NOx-limited, co-limited, or ROG-limited regime. However, preliminary conservative estimates indicate that the county airshed is not ROG-limited, thus reducing potential impact of seep capture on air quality. Also, the exact seep gas speciation at the ocean surface is unknown. In addition,

the ozone production model assumes instantaneous mixing of the gases throughout the region and ignores major outside factors such as migration of pollutants to and from the Santa Barbara Air Basin.

The ozone production model used for this analysis assumes instantaneous mixing of the gases throughout the region and ignores major outside factors such as migration of pollutants to and from the Santa Barbara Air Basin. A more thorough analysis of spatial and temporal variation of ozone production would require a more complex air model, but would probably not qualitatively alter the results of this analysis.

PART 2: Political and Economic Practicality

Having assessed the likely environmental consequences of seep tents, we now examine the political feasibility and economically practicality of the project. In Chapter 4 we discuss the potential legal obstacles to developing marine hydrocarbon seeps. In Chapter 5 we discuss the economic practicality to developing the marine hydrocarbon seeps using seep capture tents.

Chapter 4: The Legal and Political Feasibility of Installing Seep Capture Tents in the Santa Barbara Channel

4.1 Introduction

Oil and gas development has always been controversial in California, and the proposed seep tents will be no exception. Even though natural gas is a relatively clean source of energy, adding more seep tents off the coast from a major university, and issuing emission reduction credits will be debated strongly, as it is unusual for the U.S. Environmental Protection Agency (EPA) to give credits for reducing emissions from a non-anthropogenic source. It is important to understand the regulatory framework surrounding a potential development project, including installing new seep tents, pipeline, and onshore processing. The legal feasibility section will point out such general concerns, and analyze different options for the project.

Part of the controversy comes from the lack of a cohesive marine development policy. Several jurisdictions govern the actual decision making and permitting for any oil and gas development. The seeps off Coal Oil Point are at the nexus of a complicated multi-jurisdictional framework, with several and sometimes conflicting regulations applying. Even though state and federal governments have direct managerial control over their respective offshore agencies, it is the local governments that have direct control over the permitting of onshore support facilities that support offshore development. Today's offshore oil and gas development technology is dependent on the onshore support and processing facilities such as oil and gas processing plants, pipelines, supply bases, and marine terminals. The local government's direct authority and policy over such facilities becomes critical for any offshore oil and gas development, including potential seep capture tent installation.

The purpose of this chapter is to discuss the possible legal and political obstacles to developing the Coal Oil Point Seeps.

4.2 Regulatory Framework: Industrial and Energy Development in Santa Barbara County Both Land and Sea

In order to assess the relevant regulations, and the legal and political feasibility for the proposed seep tents, this project used several legal resources including literature searches and regulatory framework evaluations. The California Offshore Oil and Gas Leasing and Development Status Report (COOGLDSR) was prepared by California Coastal Commission, State Lands Commission, and Mineral Management Services at the California Secretary for Resources' request (May 25, 1999). The document provides a comprehensive history of federal and state policy and legislation that affects offshore oil and gas leases on the Outer Continental Shelf (OCS) tract lands of the U.S. West Coast.

The federal Coastal Zone Management Act (CZMA) was passed in 1972 to encourage effective state management of coastal zone resources, including offshore oil and gas activities, and associated environmental impacts in and around the coastal zone (COOGLDSR, 1999). The California Coastal Management Program (CCMP) was established pursuant to the Coastal Act of 1976 under the CZMA. The CCMP (certified in 1978) gives state consistency authority over federal activities that affect the California shoreline (COOGLDSR, 1999).

The California Coastal Commission (CCC) has direct permit authority over offshore oil and gas development out to three nautical miles (in state waters). Chapter 3, Article of the California Coastal Act of 1976 describes the standard of review for oil and gas development used by the CCC. The CCC also reviews and administers the coastal consistency determinations under the CZMA.

In 1999 there were federal (congressional and presidential) moratoria for *new* OCS leases on any area for oil and gas exploration and development (this is subject to change under the new administration). Under the California Coastal Sanctuary Act of 1994 all state coastal waters, except those under lease on January 1, 1995, are permanently included in the sanctuary established by the statute (COOGLDSR, 1999). This means that the State Land Commission cannot issue new oil and gas leases unless it determines that the lease is in the best interest of the state or the President has found a severe energy supply interruption or the Governor and Legislature act to allow further development of the OCS (COOGLDSR, 1999). None of this applies to already leased areas. The majority of the seeps are within already leased areas and areas designated as available for lease. Thus the moratoria would not directly affect the study area, because the seeps are within several lease boundaries.

At the local level, Measure A96 amended a referendum for the General Plan's Land Use Element and Coastal Land Use Plan in 1996 (COOGER, 2000). The initiative basically amends any legislative approvals at the state level to a South Coast onshore support facility development (for offshore energy) by requiring a referendum. South Coast is defined from Point Conception to the Ventura County border (COOGER, 2000). Any legislative approval of such developments will not be final unless the onshore support development is approved, in the affirmative, by a majority of the votes cast by the voters of the Santa Barbara County in a regular election. Measure A96 applies towards any development, construction, installation, or expansion of any onshore support facility for offshore oil and gas activity on the south coast. Onshore support facilities are defined as "…any land use, installation, or activity proposed effectuate or support the exploration, development, production, storage or other activities related to offshore energy resources."

Measure A96 does not apply to offshore energy development, so the installation of seep tents are not affected by this amendment. We assume that gas collected in the tents will be transported onshore (via pipelines) and processed at some onshore facility. A new gas processing facility for the seep gas would be subject to a Measure A96 referendum. Given Santa Barbara County's unfavorable views on new oil development on the South Coast, A96 may pose a threat to a seep development project. It is unclear if the pipelines,

which will probably go on land at some point along the South Coast, are considered an onshore support facility (which would be subject to Measure A96). Additionally, Measure A96 does not apply to future activities planned in the two South Coast "consolidation" sites at Las Flores Canyon and Gaviota.

Developing infrastructure to support the proposed seep tents will be an important determining factor when assessing the viability of the project both legally and economically. The California Legislature recognized in section 30001.2 of the Coastal Act that although offshore petroleum and gas development may have significant adverse effects on coastal resources and coastal access, it might be necessary to locate such development in the coastal zone in order to ensure that inland and coastal resources are preserved and that orderly economic development proceeds within the state. Thus, the Coastal Act distinguishes between coastal- dependent and coastal- related criteria when considering new industrial development in the coastal zone. Coastal- dependant development or use means any development or use that requires a site on or adjacent to the sea to be able to be functional at all. Examples of this include development of oil and gas reserves located offshore and in the coastal zone. Coastal- related development means any use that is dependant on coastal- dependant development or use. Examples of this include the processing plants that are necessary to support the development of oil and gas reserves such as refineries. Whether or not the location of such a facility is appropriate in the coastal zone will be made on a case-by-case basis (SBCCP).

Under section 30255, coastal- dependant developments are given priority over other shoreline development projects. Coastal-dependant developments cannot be sited in wetlands. Section 30260 of the Coastal Act recognizes that coastal-dependant industrial and energy development may not be consistent with other Coastal Act policies but may be necessary for public welfare. Thus, oil and gas development is permitted if it is found that the project is feasible subject to the policy constraints found in Chapter 3 of the Coastal Act. Coastal-dependant oil and gas development must meet the following criteria set forth in Section 30260:

(b) New or expanded facilities related to such development are consolidated, to the maximum extent feasible and legally permissible, unless consolidation will have adverse environmental consequences and will not significantly reduce the number of producing wells, support facilities, or sites required to produce the reservoir economically and with minimal environmental impacts.
(d) Platforms or islands will not be sited where a substantial hazard to vessel traffic might result from the facility or related operations, determined in consultation with the United States Coast Guard and the Army Corps of Engineers.

Part (b) of section 30260 will affect how the infrastructure of a seep capture tents project will ultimately look. It is very important that the amount and impact of infrastructure on land be minimized to the fullest extent possible while acting in accordance with all regulations. This is unlikely to be a problem given that most projects by nature act to minimize cost, which implies that they would implement the most efficient options available for infrastructure.

Part (d) of section 30260 will be of critical importance. It will essentially determine the locations and heights of potential seep capture tents. If tents were to be moved around to take advantage of the highest rates of seepage then it will likely require additional analysis by the Army Corp of Engineers and the Coast Guard. Permitting will be a very costly part of the venture (on the order of $200,000).

Section 30263 establishes the criteria used to situate refineries in the coastal zone:

(a) New or expanded refineries or petrochemical facilities not otherwise consistent with the provisions of this division shall be permitted if (1) alternative locations are not feasible or are more environmentally damaging; (2) adverse environmental effects are mitigated to the maximum extent feasible; (3) it is found that not permitting such development would adversely affect the public welfare; (4) the facility is not located in a highly scenic or seismically hazardous area, on any of the Channel Islands, or within or contiguous to environmentally sensitive areas; and (5) the facility is sited so as to provide a sufficient buffer area to minimize adverse impacts on surrounding property.

Part (a) of Section 30263 of the Coastal Act implies that new facilities will not be developed unless existing facilities are used at maximum capacity. At the moment, the Ellwood marine terminal is under utilized (COOGER, 2000). However, it is not clear from the legal language if this prohibition is referring to the design capacity or the permit capacity. Nonetheless, it is unlikely that a project would be able to permit for its own refinery to process seeps gas.

It is unlikely that a seep capture project will have its own refinery; it will likely use an existing processing facility. In order to determine likely candidates, a significant amount of information was obtained from the recently released California Offshore Oil and Gas Energy Resources Study (COOGER study, released 2000). COOGER is a comprehensive report that addresses the concern about the likely future demand on the onshore facilities from future offshore oil and gas development in the Tri- County area (Ventura, Santa Barbara, and San Luis Obispo). COOGER was designed by an intergovernmental work group, under a Minerals Management Service Contract, but in cooperation with several state and local jurisdictions. COOGER evaluates in detail, the current regulatory framework that governs the development of offshore gas and any required onshore support/processing facilities and infrastructure. It presents the onshore infrastructure, including the designed and permitted capacities of those facilities as of 1995.

Production of gas from the Elwood Field is in a state of decline and consequently, the four Elwood onshore processing facilities process less oil and gas than they were designed to (COOGER, 2000). The combined oil production from these facilities appeared to have peaked in the mid 1990's, and are projected to decline annually through the end of 2015 (end of study year) (COOGER, 2000). As a result, these facilities are expected to have increasing spare capacity during this period of reduced production. Spare capacity for oil and gas refers to the theoretically available capacity of a processing plant when the processed oil and gas is less than the design (or permitted) capacity.

The Elwood Oil and Gas Processing Facility does not have excess capacity available to production sources other than Platform Holly and the associated ARCO seep capture tents (COOGER, 2000). Collected gas is sent ashore via a pipeline. Although the design capacity for the facility is 20 MMCFD of gas, there are air pollution requirements that limit the facility to 13 MMCFD of gas (COOGER, 2000). Another limitation on the Elwood Facility is its current classification as a legal non-conforming use, which means that it is land use zoning changed from industrial to residential (COOGER, 2000). This status severely limits potential future modification or expansion of the facility, or its operation permits. Any changes to the facility must either be required by law, or to reduce significant impacts, and any proposed changes require Santa Barbara County review and approval and California Coastal Commission certification (COOGER, 2000).

Future production estimates by the former operator Mobil predicted the quantity of oil and gas produced from Platform Holly to decline annually over the life of Holly and the facility (in absence of new development) (COOGER, 2000). As mentioned above, future modifications and receiving oil and gas from other sources are severely limited and prohibited respectively with current Santa Barbara County law. Based on these projections and limitations, the facilities economic life would end by the study year 2010 (in the absence of new development) (COOGER, 2000).

Venoco, which is the current operator (of Platform Holly and the facility), is investing in existing wells and facilities to extend the economic life of Holly and the facility. In such a case, the facilities input of natural gas to the Southern California Gas Companies distribution network would also end. No plans to expand current development have been announced as of August 1999 (COOGER, 2000).

4.3 Permitting Marine Hydrocarbon Seep Development

The necessary approvals to develop Coal Oil Point Seeps include: reporting to the Minerals Management Service (MMS) for approval of their plan for development or production, and a coastal consistency determination (provided to the CCC) that the proposed activity complies with the CZMA and CCMP. In addition, other federal, state and local approvals will be required depending on the design of the development plan. (These include the U.S. Army Corp of Engineers, U.S. EPA, U.S. Fish and Wildlife Service, California State Lands Commission, U.S. National Marine Fisheries Service, and the Local Air Pollution Control District). Furthermore, county voters will need to approve of the onshore support facility, as is their right given to them by Measure A96.

4.4 Revenue Streams and Taxes

A marine hydrocarbon seep development project will contribute to federal, state and local revenues through direct payments to local agencies, state taxes and federal contributions of a portion of royalty revenues to state and local programs (COOGER, 2000) Four cost streams are of particular interest to an offshore development project: property tax, income

tax, permitting fees and mitigation fees. The natures of these fees are difficult to discern given that there are no currently proposed plans of sufficient specificity. Property subject to taxation could include the seeps tents and its supporting infrastructure including the refinery. Permitting and mitigation fees are assessed by various agencies and are given to special programs designed to manage and/or mitigate potential consequences of offshore development projects (COOGER, 2000). The amounts of these fees will also vary by what the development entails.

4.5 Emission Reduction Credits

The economic profitability of installing new seep tents will be enhanced if the EPA or Air Pollution Control District allocates emission reduction credits for the capture of seep gas. Emission reduction credits (from here on referred to as credits) are an agreement between a company and the EPA or County Air Pollution Control District, allowing the company to emit a certain amount of a polluting substance in return for reducing polluting emissions elsewhere. The credit can be used within the same company or transferred between companies. Either way, the credits have significant value. Used within the same company, the credits allow operations to be authorized that would not have otherwise been permitted.

ARCO received credits for their 1982 seep tents project, and they were central to its economic success. In 1981 ARCO and Santa Barbara County made an agreement that used California's new emission offset policy. As a preliminary step in the project, ARCO hired a consulting firm to measure the composition of the seep gas and estimate the emission rates. These data were used to determine the amount of emission credits given (Rintoul, 1982). The agreement allowed them "interpollutant tradeoffs:" the county's Air Pollution Control District required them to remove 1.2 parts hydrocarbons for each part of nitrous oxides (NO_X) emitted in future drilling. Credits were only given for non-methane hydrocarbons (Rintoul, 1982).

The credits were very valuable to ARCO because they allowed the drilling of two new wells during the drilling-moratorium that followed the 1969 Santa Barbara oil spill. The contract with the County gave the oil company an advance on their emission credits before the seep tents were even installed. Specifically, they were granted emission reduction credits in the value of two tons of reactive hydrocarbons per day, allowing them to drill two wells—state 309 numbers eight and nine (Rintoul, 1982). The company started exploratory drilling immediately, which eventually led to oil discovery. After seep containment began, the company was allowed to record any excess reductions, and bank them for future use as credits. However, the unused credits depreciated linearly from years five to ten. ARCO was banking over six tons per day of hydrocarbon emissions credits after the tents were operational (Rintoul, 1982).

The credits greatly increased the viability of ARCO's 1982 project. In fact, ARCO's Guthrie and Rowley wrote in their project summary that, "This project would not have

been attractive economically without incentives. The daily gas production rate is not substantial enough to be a break-even venture, let alone be profitable"(5).

Would a seep tent project be eligible for emission reduction credits today? At the time of this report, the Santa Barbara County Air Pollution Control District had not confirmed whether or not credits could be given for this project (Allard 2002). It was stated that the credit awards are contingent on two primary factors. Before even being considered, the installer of the tents would have to document the amount of reactive hydrocarbons that they removed; neither ethane nor methane is considered reactive. As the first step in applying for emission credits, the applicant must demonstrate that the reductions are permanent. This would be difficult to prove for a seep tent project due to the temporal and spatial fluctuations of the Coal Oil Point seeps. However, it may still be possible to receive a temporary offset credit. A second factor in determining credit allocation by the EPA is that the reduction must be surplus to the attainment of federal air quality standards. If both of these first two criteria are met, then the project still faces one additional hurdle before receiving credits. The SBCAPCD inventories sources of air pollution in the county for the EPA, but that inventory does not include natural sources. Therefore, the seeps are not currently on the list of polluting sources, and thus are not eligible for credits (Allard, 2001; Allard, 2002). An exception would have to be made for this project to receive credits, and at present it is not clear what the probability of successfully receiving credits would be.

If credits *were* awarded, what would they be worth? Director Allard stated that the going market for an emission credit worth one ton of ROGs is approximately $5,000. However, reducing air pollution from a natural source might not be valued as highly as that from an anthropogenic course. One ton of ROG credits might be discounted by 20%, resulting in 0.8 tons of ROGs credits being acquired by firm for reducing one ton of ROGs. This effectively makes the value $4,000 for reducing one ton of ROGs. In addition, further discounts are applied when the credit is used (Allard, 2001; Allard, 2002). Due to the multiple uncertainties in both credit allocation and value, economic model scenarios were run both with and without credits (see Section 5.8).

4.6 Conclusions

There are several regulatory complications that limit the likelihood that seep gas is sent to a new onshore processing facility. Measure A96, requiring voter approval for onshore infrastructure for offshore projects, would be an obstacle because the project will be dependent on the county voters approval of such a facility. If that measure is passed, then there is the remaining suite of permits that will need to be acquired. Given the current sentient about offshore oil and gas development, this will be a risky portion of the permitting that will take much time and would limit the ability and timeliness of the project.

If the seep gas were sent to an existing onshore processing facility, then the most likely facility that would receive and process the seep gas would be the Ellwood Oil and Gas

Processing Facility. The existing tent captured gas is already processed there, and it is the closest onshore support facility to the seep field. Further limitations may come from the Coastal Act sections explained above (30263), which implies that new facilities will not be developed unless existing facilities are used at maximum capacity. The Ellwood facility is currently under-utilized, but is currently designated as a non-conforming use because the land use zoning changed from industrial to residential. However, it is not clear from the legal language if this prohibition is referring to the design capacity or the permit capacity.

Finally, the project's economic feasibility relies on emission reduction credits, as shown in the following chapter, yet they are unlikely to be awarded by the EPA for installation of new seep tents. Federal credits are not feasible politically for three reasons: 1) it would be difficult to prove that seep tents would permanently reduce ROGs and ozone; 2) Santa Barbara is already in attainment for federal ozone standards, precluding the award of credits for ozone; and 3) the seeps are a natural source of ROGs, and therefore a special exception would have to be made to award credits to a project that reduced seep gas. If awarded, the credits would most likely be worth $4,000 per 1 ton of ROGs reduced, taking into account an 80 percent discount from ROGs reduced to ROGs used to calculate credit awards. An alternative to the formal EPA-issued credits considered in this study would be to investigate the potential for local credits issued by county agencies.

5.1 Introduction

One of the deciding factors in the viability of a new seep tents project will be economics. Though the ecological effects of the project are not monetized in this report, the viability and the value of several project scenarios are evaluated below. Two views are taken throughout this section, one of an entrepreneur's assessment of the project as a business, and the other of a policymaker's assessment of the social value of the project. The quantification has four primary components: the revenue from gas sales; the non-market value of health benefits from reduced ozone; the value of emission reduction credits, if acquired; and the costs of capital, installation, and maintenance. Each element is a component in the net project value, described first in the mathematical model below. Section 5.3 of this chapter explains the natural gas pricing models, and 5.4 the valuation of health benefits. The following section describes the cost-benefit analysis computer model and its parameters, and then the most likely project scenario is presented in Section 5.6. A sensitivity analysis of the most likely scenario follows in the next section. Five other important scenarios are then presented in Section 5.8.   Section 5.9 includes an economic analysis of cost-benefit model results including the average costs of ROG reduction and ozone abatement, and the valuation of methane emission reduction in the global emissions trading market. We present our conclusion in Section 5.10.

5.2 Economic Model

The mathematical description of our project valuation is shown below in Equation 1:

$$V(i) = \sum_{t=2}^{t=22} \frac{[g_{ti}(P_t - p_t)]}{(1+r)^t} + \sum_{t=2}^{t=22} \frac{h(z_{ti})}{(1+r)^t} + \sum_{t=2}^{t=22} \frac{C(e_{ti})}{(1+r)^t} - \sum_{t=2}^{t=22} \frac{L_{ti} + M_{ti}}{(1+r)^t} - K_i - I_i$$

Equation 1. Project valuation model.

The purpose of this model is to calculate *V,* the net present value of the project for *i* number of tents summed over the project lifetime of 22 years. The number of tents is an important variable because it determines not only the project's engineering costs, but also the amount of seep gas captured. Gas capture directly determines the value of health benefits and emission reduction credits. A value is calculated for every year of the project, from year *t* = 2 when installation is complete, to year *t* = 22, the end of the project. A project horizon of 20 years is chosen for two reasons: first, to compare hypothetical scenarios to the ARCO tents which have been operating for 20 years, and second, to stay within an acceptable timeframe for forecasting natural gas prices. The first term in the equation is the revenue from natural gas sales; this value is the sum of *g,* the average gas flux in year *t* (methane in MCF), multiplied by the difference of *P,* the average price of gas in year *t* ($ per MCF), less *p,* the processing and handling cost (per MCF). The second term is the health benefit from reduced ozone, *h* ($/year), which is a function of *z*, the change in ozone in year *t* as a percent

of the county average. Third is the value of emission reduction credits, C ($), a function of e, the tons of ROGs reduced per year. Finally, the costs are subtracted, including the maintenance costs for the tents and pipeline, M ($/year) and L ($/mile/year), respectively. Capital and design costs, K ($), and installation costs for the tents and pipeline, I ($) are both a function of the number of tents.

This conceptual mathematical model is used to construct a cost-benefit analysis model to quantitatively evaluate project scenarios. Both the mathematic and computer models synthesize several individual components—a gas-pricing model, a health model, and calculations for emission reduction credits and capital and maintenance costs. Each of those components is described below, followed by an explanation of the cost-benefit analysis model, and how it integrates all elements.

5.3 Natural Gas Time Series Analysis and Forecasting

For the purposes of this paper, it is necessary to predict future natural gas sales from the potential seep tents. Several methods to forecast natural gas prices are used including ARIMA, Hotelling, and Structural models[2]. California City Gate natural gas prices for the time period of January 1989 to July 2001 were obtained from the United States Department of Energy Website (2001).

The historical data obtained from the Department of Energy is shown in Figure 8. There is no obvious trend in the prices over time, which implies that a Hotelling method of forecasting may not be appropriate for gas as opposed to other natural resource pricing models. Also, a large price shock occurred in 2000-2001. Although none of the forecasts we make predict a price shock in the next 20 years, it is important to realize that price shocks may happen again. Figure 8 below shows the historical data used to forecast future gas prices, including the price shock period.
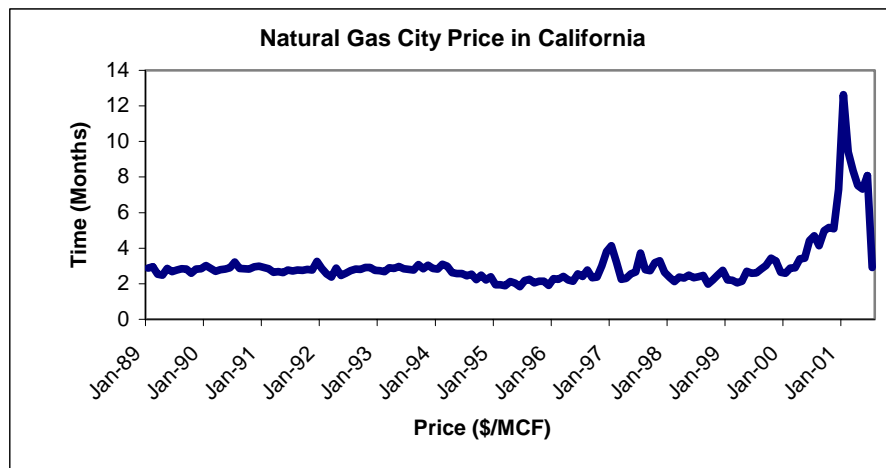
Figure 8. Natural gas city gate prices in California from January 1989 to July 2001.

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[2] Forecasting methodology and cited sources are found in Appendix A.

5.3.1 Forecast

The four 20-year price forecasts and their relation to the historical city gate prices are illustrated in Figure 9. Additionally, Table 10 illustrates the average annual price predicted for the next 20 years using the four different price forecasting models. The four forecasts depicted in Figure 9 will be used as a part of our integrated analytical model. Details of the computations can be found in Appendix A.

Table 10. Average annual natural gas price predictions for the next 20 years from four methods of forecasting.

Pricing Model	Forecasted Annual Average Price ($/MCF)
Conservative ARIMA	$2.45
High ARIMA	$6.09
Structural	$3.00
Hotelling	$6.01
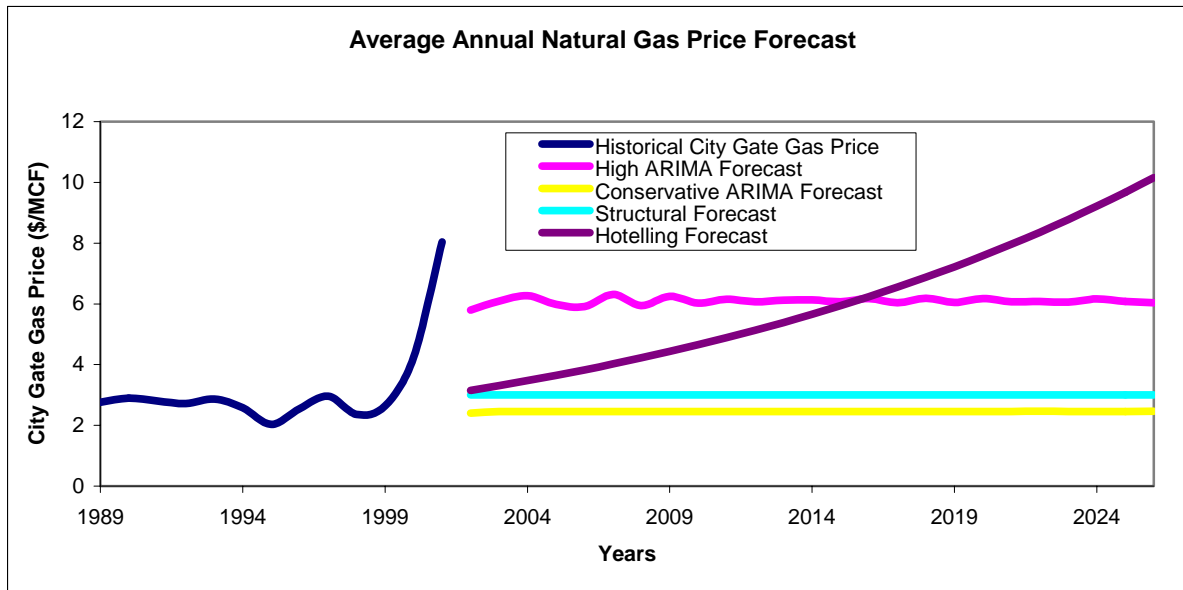
Figure 9. Natural gas price forecasts for the next twenty years using four different modeling schemes.

Four forecasts of the city gate natural gas pricing are used: Structural, Hotelling, Conservative ARIMA, and High ARIMA. Each of the models is described in the natural gas pricing appendix (Appendix A). The numerical values for the gas pricing are valued to present and then used to calculate the profitability of the project over its lifetime. The forecast is selected when the words "High", "Conservative", "Hotelling" and "Structural" are entered in to the appropriate cell.

5.4 Valuation of Health Benefit from Reduced Ozone

This section values the health benefit from improved air quality caused by tenting the seeps. As reported in Chapter 3, capturing the seep gas may reduce ozone, an important air pollutant in the county. Numerous studies have shown that ozone is harmful to health, and although the health benefits of lower ozone concentrations in Santa Barbara County have not previously been valued, techniques exist to calculate the economic benefit. Non-market valuation methods have been used in other cities to measure the health effect of changes in ozone levels and its associated dollar value. Recently, the EPA report entitled "Benefits and Costs of the Clean Air Act 1990 to 2010" (BCCAA) catalogued all studies that value health benefits from reduced ozone to compare them to the costs of U.S. national ambient air quality standards from 1990 to 2010 (EPA-1, 1999). The purpose of this section is to use the dose-response functions and health benefit values from the studies compiled in the EPA's report to estimate the health benefit from the amount of ozone potentially reduced from capping natural hydrocarbon seeps. This approach is called "benefits transfer" because it uses Santa Barbara data, but also applies data from other cites as proxies for local information. It is important to note that since we use a benefits transfer approach, this estimation is not entirely specific to Santa Barbara County.

5.4.1 Benefits Transfer Calculation

To calculate the health benefits from ozone reduction by seep capture tents, we use the dose-response functions and coefficients listed in the EPA BCCAA compilation of studies, inserting available Santa Barbara-specific information. The study predicts values for the following eleven illness categories with more than one valuation study for some illnesses:

- Acute Respiratory Symptoms: the presence of any of 19 various respiratory symptoms in the adult population ages 18 to 65.
- Adult Onset Asthma.
- Emergency Room Visits – Asthma.
- Hospital Admissions – All Respiratory Diseases (Calculated for (1) entire population and (2) elderly population of 65+ years of age).
- Hospital Admissions – Asthma.
- Hospital Admissions – Chronic Obstructive Pulmonary Disease (COPD): includes such chronic diseases as bronchitis, emphysema, asthma, and others. Its effect is only calculated on the elderly population (65+).
- Hospital Admissions – Respiratory Infection.
- Minor Restricted Activities Days (MRADs): result from both respiratory and non-respiratory conditions, but generally encompass minor symptoms such as shortness of breath, coughing, soar throat, and eye irritation. These results are calculated for the adult population only (ages 18-65).
- Mortality.
- Self-Reported Asthma Attacks.

Most of the studies present different functions for the ozone to health relationship, and all have different coefficients. Each of the functions includes the rate of illness per person, a coefficient relating the ozone level to the change in health, the change in the ozone concentration in ppb, and the population of the study area. Using literature values from the EPA BCCAA report, the annual dollar value of this change in health is calculated. A complete review of the calculations necessary to achieve the valuation for each category is provided in Appendix B, as well as a discussion of the limitations of each health effect category, the study authors and associated cities.

Each EPA BCCAA study determined the rate of illness per person and the relationship between ozone level and the change in health from either hospital admissions or survey data and ambient ozone levels in a specific city or area. Area-specific information for Goleta-Santa Barbara is not available to incorporate into the functions. Instead, coefficients given in the studies are used.

The ozone reduction amount that is calculated in Chapter 3 is inserted into the health benefit functions. That value is given as a percentage reduction, and so to generate an outcome in ppb, it is multiplied by the average county ozone concentration in ppb as listed on the SBCAPCD website.

It is unlikely that the entire population of the county is affected by seeps-caused air pollution; therefore only the population of the cities of Santa Barbara and Goleta as recorded in 1999 Santa Barbara County census data are included in the model. Several of the studies' functions focus on either the elderly or adults only, therefore the population is corrected in those calculations using 2000 Santa Barbara County census data (US Census Bureau, 2001).

Valuation results are determined for each of the eleven categories of health effects. The dose-response functions give the number of reduced incidences of each illness per year. An incidence is one occurrence of the illness. Many of the reduction values are less than one implying that, statistically speaking, less than one incidence of the illness is reduced per year. Dollar values for illnesses are taken from the EPA BCCAA report, which are based on a number of previous studies using willingness to pay and cost of illness valuation methods (U.S. EPA). The incidence reduction is multiplied by the incidence value to give a final dollar value for the ozone reduction for that illness.

5.4.2 Health Valuation Results

The quantitative results show that the greatest value of all of the eleven illness categories is from the reduction in risk of mortality, followed only by the reduction in incidence of chronic diseases. The specific valuation results for this study are shown in Table 11. For each of the illness categories, the predicted number of incidents

reduced by the most likely[3] project scenario is shown, as well as the value for that type of health incident and the resulting reduction value for the project.

Table 11. Health benefits from most likely project scenario in terms of incidence reduction.

Incident Type	Predicted Number of Incidents Reduced by Project	Value of One Incident ($)	Reduction Value ($)
Mortality[A]	0–0.122	$1,500,000.00–$9,000,000.00	$0.00–$1,098,000.00
Hospital admissions-COPD[2A]	0.00039–0.00064	$260,000.00	$101.40–$166.40
Adult onset asthma[1]	0.6792	$25,000.00	$16,980.00
ER visits-asthma[A]	0.00027–0.0034	$194.00	$0.00–$0.06
Hospital admissions-asthma	0.00036	$32.00	$0.01
Self-reported asthma attacks	0.08	$32.00	$2.56
Hospital admissions-all respiratory[A]	0.0005–0.0038	$18.00	$0.01–$0.07
Hospital admissions-all respiratory[2A]	0.0012–0.0032	$18.00	$0.02–$0.06
Hospital admissions-respiratory infection	0.00092	$18.00	$0.02
Presence of any of 19 acute respiratory symptoms[3]	2.56	$18.00	$46.08
Respiratory and non-respiratory conditions resulting in MRAD[3]	0.878	$5.30	$4.65

*If a reduction in incidence has a value of less than 1.0, then the results can be interpreted as a reduction in the chance of an incident occurring. [1]Population over age 18 males. [2]Population age 65 and older (12.7%). [3]Population age 18 to 65 (62.4%). [A]Average of results from more than one study.

The chart in Figure 10 shows the percent distribution of each illness category. As benefits other than mortality risk reduction are more than an order of magnitude lower, their percentage distribution relative to the others is shown in Figure 11. Again, chronic disease comprises the majority, while acute symptoms account for the remainder.

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[3] Most likely scenario is defined in Section 5.6.
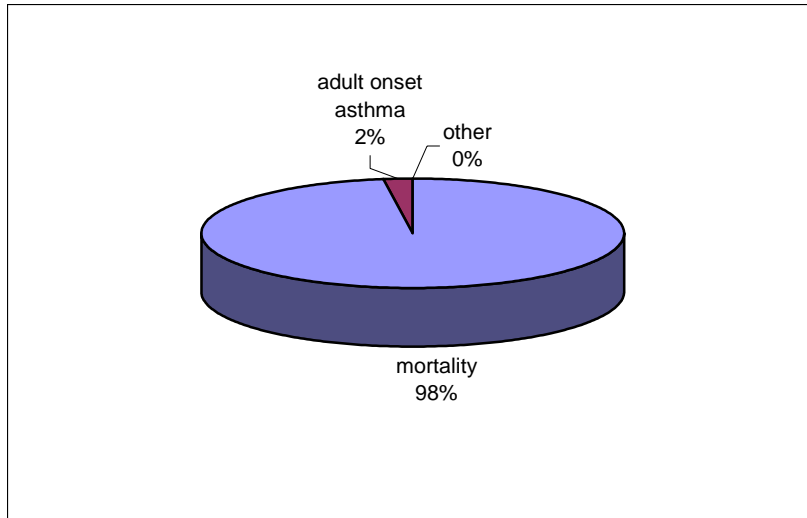
Figure 10. Percentage distribution by illness of benefit from ozone reduction due to seep capture.
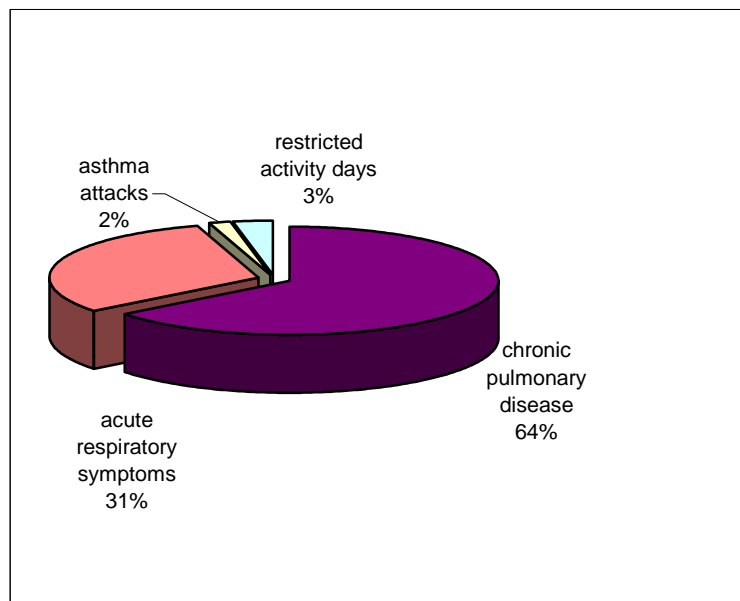
Figure 11. Percentage distribution by illness of benefit from ozone reduction (excluding mortality and adult onset asthma).

The value for mortality reduction is particularly subjective because it depends on the value of a statistical life that is chosen. Two literature values of a statistical life are thus used for comparison. The first is a value of $9 million. The study is appropriate for this assessment because it was derived from a contingent valuation survey of asthma control and risk valuation (O'Conor & Blomquist, 1997). The second study surveyed low-level environmental risk valuation and gives a value of $1.5 million for a comparable risk reduction (Carson & Mitchell). Results are calculated from both

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values for comparison, and shown in Table 12, yet the second is more realistic because it falls within the range of generally accepted values.

Table 12. Value of mortality risk-reduction from differing reductions in risk and for two values of a statistical life for the first year of tent capture under the most likely scenario assuming co-limited ozone production.

Study (mortality reduction)	Value at $1.5 M per statistical life	Value at $9 M per statistical life
Ito & Thurston (8.3%)	$177,354	$1,064,121
Kinney et al. (0%)	$0.00	$0.00
Moolgavkar et al. (8.0%)	$170,920	$1,025,521
Samet et al. (12.2%)	$261,822	$1,570,933

Three estimates of health benefits from a small reduction in ambient ozone concentration are calculated from the data listed above to give high, middle and low estimates for the overall benefit; this range is shown in Table 13 (see Appendix B for a full list of values).   The benefits are calculated using the high, middle or low value within the illness category if it uses more than one study; if there is only one study, that one value is used for all estimates. The range in the values is due to dissimilarity in the base study cities or regions.

Table 13. Three estimates of health benefits from ambient ozone reduction for 1 tent over a 20-year project life.

Health Benefit Estimates	Dollars
High estimate	$17,900,000
Middle estimate	$2,100,000
Low estimate	$160,000

When evaluating the validity of the estimates in Tables 14 and 15 several limitations of this benefits transfer valuation exercise must be considered. First, the air quality model we use to calculate the change in ozone from seep tent installation overstates the reduction due to high seeps speciation estimates (see Chapter 3 for a full discussion of the limitations of the air quality model). Second, the ozone and illness incidence variables from the dose-response functions are not specific to Santa Barbara. Each of these coefficients is calculated from a specific population in another North American city; because Santa Barbara's level of air pollution is relatively low compared to the many of the study cities like Los Angeles, California, and Detroit, Michigan, this difference would cause an overstatement of the final values. Similarly, population demographics are different in Santa Barbara than the other cites, though without statistically analyzing the differences it is again unclear in which direction this would bias the results. The studies' coefficients are calculated using the ambient ozone levels of the study city, and because Santa Barbara's average ambient ozone levels are relatively low and are generally below the legal standards the same reduction may not have as great a value. Finally, differences in the cost of living would also affect the value, but as Santa Barbara is a relatively expensive city

in which to live, this would cause an underestimate of the benefit dollar values, which are averages for the nation.

In conclusion, as the health benefits valuation studies used by the EPA are from many cities across North America they also range over different characteristics, yet give similar results, so perhaps the benefits transfer method is more accurate than was originally thought. Even with these limitations taken into account, the benefits transfer valuation gives a range of estimates from $160,000 to $17,900,000 with the most likely value being $2,100,000 for a one-tent project that creates a 0.4 percent reduction in ozone. The integrated model described below evaluates projects ranging from one to 20 tents, and thus calculates different levels of ozone reduction and health benefits for each scenario. The low, medium and high levels of health benefit values defined above are integrated into the model for the evaluation of numerous seep tent project scenarios.

5.5 Cost – Benefit Analysis Model

We developed an analytical model to help analyze different project scenarios. The model synthesizes the results of the health benefit valuation and air quality models, and values of gas price forecasts, emission reduction credits, and maintenance and capital cost estimates. More than 17,000 project scenarios can be calculated from our defined parameter values; in addition, the majority of the parameters can be set to a value other than that which we have defined—creating the opportunity to generate thousands of other scenarios. The section below describes each of the model's parameters. We used our background research to identify a "most-likely scenario." This scenario is presented after the parameter definitions; it is followed by an explanation of how each parameter's most likely value is selected. Section 5.7 then evaluates the sensitivity of the model to each of the variable parameters. Finally, after multiple model tests encompassing many project scenario possibilities, several scenarios are chosen to highlight this study's important findings regarding potential seep tent installation—these are shown in Section 5.8.

5.5.1 Parameters for Cost Benefit Analysis

Although all of the model parameters are changeable, several are held constant throughout our analyses, and are not altered because their value is believed to be the single best estimate of that data. These parameters are:

Total flux of the seep field

The best estimate of the gas flux from the entire study area is 100,000 m^3 per day. This constant is used in the ozone production model to compare a seep tents project's reduction in emissions to the total emissions flux from the field. This data has been estimated by the UCSB Hydrocarbon Seeps Research Group (UCSB Hydrocarbon Seeps Project, 2001).

Capital and design costs

Peter Cantle of the SBCAPCD provided the original capital and design cost estimates (2001). These estimates were: for a project with one to two tents, a cost of $2 to $4 million dollars per tent; and for a project with 10 tents, a cost of $1 to $2 M per tent. To capture a single cost estimate for each potential number of tents a linear average cost per tent function is determined (

Figure 12). For one through nine tents (T = number of tents) that function is: $3,000,000 * (T) – $75,000 * (T²). For 10 to 20 tents the function is: $22,500,000 + $1,500,000 * (T – 10).
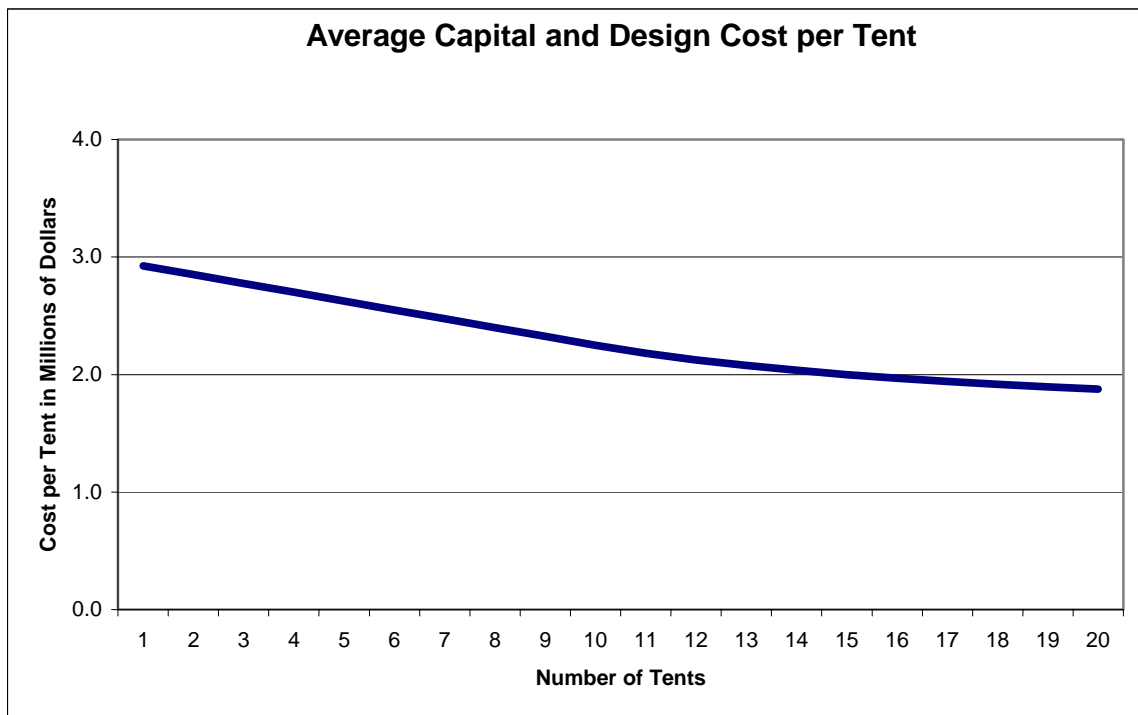
Figure 12. Average capital costs per tent for 1 to 20 seep tents. Piping costs are included.

Installment Costs for Piping

Installation costs for piping are assumed to be $1 M per mile (Cantle, 2002). A cost is estimated based on the existing seep tents, which are located 3.8 miles from their processing plant. Thus a base cost is assumed of $3.8 M. If multiple tents are proposed, they are assumed to use an additional 100 feet of piping per tent, making the piping cost range from $3,818,939 for two tents to $3,970,451 for 10 tents and $4,159,841 for 20 tents.

The possibility exists that the seep tents could tie in to existing pipe infrastructure at platform Holly. If piping costs are not included and project costs are assumed to only include the maintenance costs and the cost of capital shown in Figure 12, the project value increases from negative $3 million to positive $400,000 and the project loss from negative $5 million to negative $1.6 million. Exclusion of piping costs does not affect the economic feasibility of seep tents, but the margin by which the project is not profitable becomes much smaller.

Maintenance Costs of Tents

The maintenance cost is assumed to be $100,000 per tent per year (Cantle, 2001).

Average Ozone Concentration in Santa Barbara County

Average ozone concentration, as reported by the SBCAPCD, ranges from 30 to over 60 ppb in current hour, one hour, and eight-hour daily maximum measurements (SBCAPCD-5, 2002). A conservative estimate of 35 ppb is used in all initial calculations, however this variable may be changed in the model if desired. A sensitivity analysis of this parameter is particularly useful (please see Section 5.7).

The remaining parameters are varied to create different project scenarios; however, except number of tents, each parameter only has between one and four value options. The parameters and value options are:

Starting Tent Flux Capture

We acquired the only data available describing the spatial flux of seep gas (flux, latitude, longitude) from Libe Washburn of the UCSB Hydrocarbon Seeps Research Group. Briefly, the researchers designed a tow-able buoy to capture and measure seep gas emissions just below the surface of the water (Washburn, Johnson, Gotschalk, & Egland, 2001, and Egland, 2000). It is important to note that several factors in the data collection lead to sampling error, specifically the choice of tow locations and the effects of surface waves on the pressure-sensitive measurement device. The introduced error limits our options for spatial analysis of the data. However, we are able to use it to estimate the flux capture of potential new seep tents. The data show that the seep gas flux is stronger in some places than others, making the strong flux locations the optimal spot for placing seep capture tents. Because there are only a few of these optimal locations, the amount of seep gas captured decreases for each additional tent (see
Figure 13). Our results suggest that the first tent captures the most seep gas, while the structurally identical second tent captures less than 15 percent of what the first does. A full description of this parameter function's derivation is provided in Appendix C.
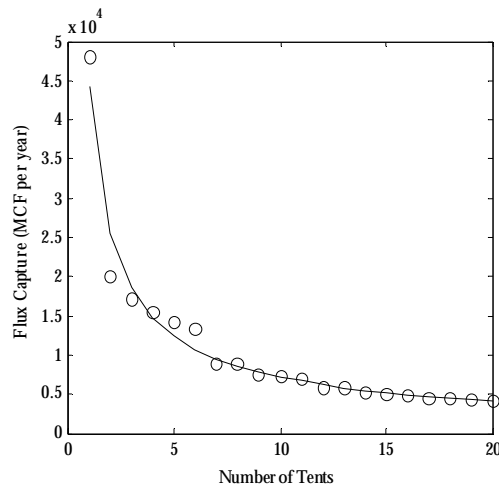
Figure 13. Plot of actual flux capture per tent (circles) and function fitted to this data (line).

Flux capture from the ARCO tents, now owned and operated by Venoco, has been recorded since installation in 1982. This dataset was acquired from Jim Boles of the UCSB Geology Department, and is used to create the best predictions of future flux capture. The monthly capture data for both tents is converted to annual flux per tent, and three illustrative values are chosen for the estimates: the starting capture of the tents in 1982, the highest capture recorded for the tents (in 1988), and the current (2000) capture. We then apply the function derived from Washburn and Egland's data to these starting flux captures to change the intercept of the function, but not the form. This procedure creates the flux estimates illustrated in Figure 14.

These results are incorporated into the final cost-benefit model as a formula that recalculates the total flux capture for one to 20 tents depending on the number of tents and starting flux value.

Of the three flux values considered, the one representing the starting flux of the 1982 tents project is the most likely (220,000 MCF/tent/year). The highest flux would be an overestimate for the starting value, though it could potentially be reached at some point in the project life. The current flux would be an underestimate because it is known that the seeps move and decline over time, so that the location for the 1982 tents probably is no longer optimal, and a new optimal area could be found with a higher flux.

53
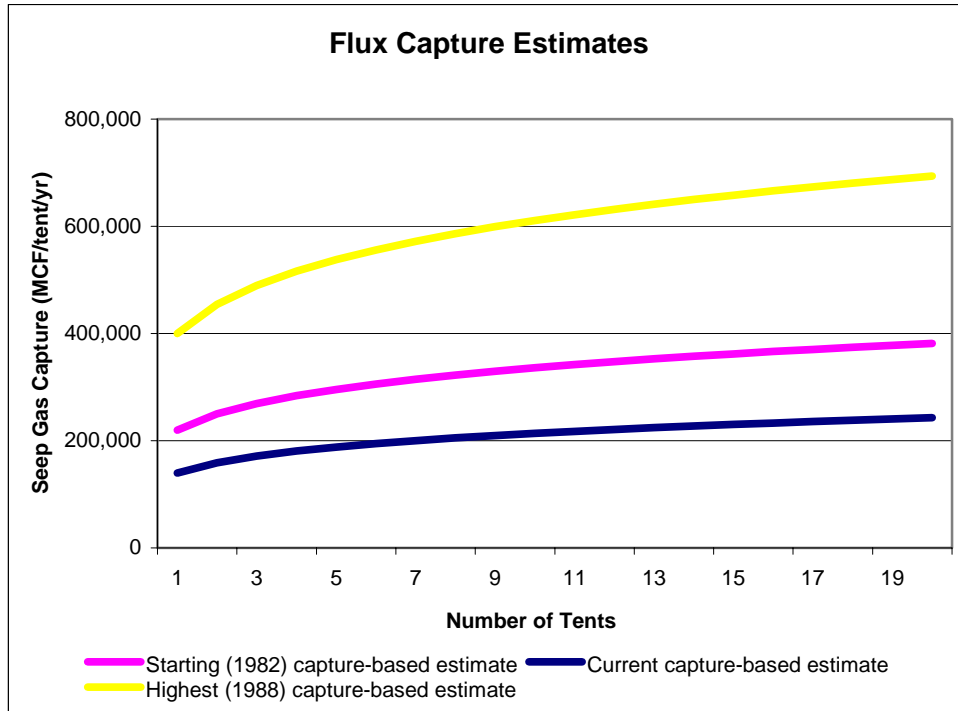
Figure 14. Flux-capture best estimates for three starting flux values (1-20 tents).

Decrease in Flux Over Time

It is known that the Coal Oil Point Seeps flux varies temporally and spatially (Quigley 1997). This variation will affect the amount of gas captured by the potential seep tents. The amount of gas the ARCO seep tents captured shows the variation of seep field flux over time; this data is used to help define the variation of the seep field flux (see Figure 15).
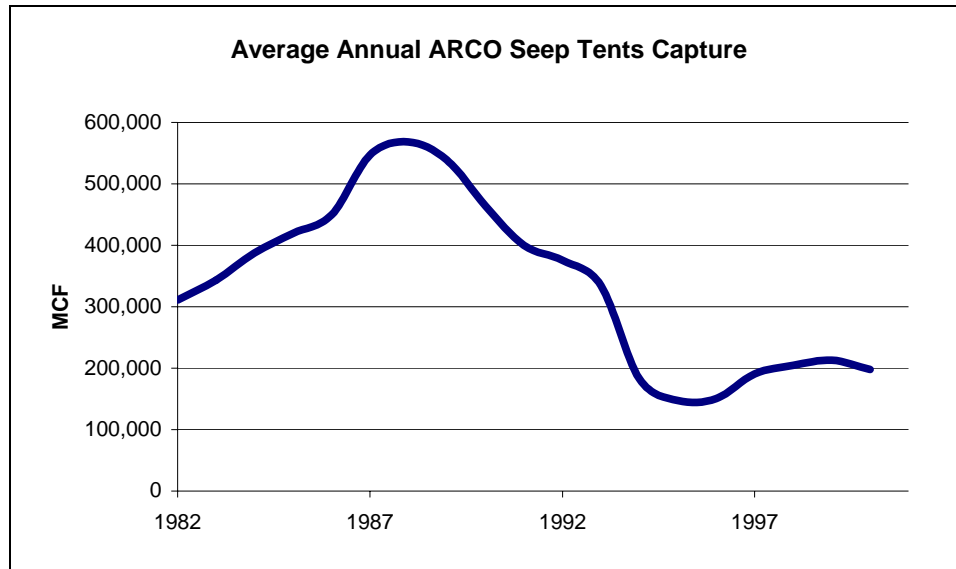
Figure 15. Historical ARCO seep tents capture from 1982 to 2000.

In order to mimic the variation, a linear regression is performed on a simple decay model with the variables of time (t) and flux. This regression results in a 7.4 percent average annual rate of decline, which we assume as the temporal decline in seepage. While hypotheses as to the amounts of variation may vary, it is important to include the possibility of a decline in seep gas capture over time in the cost benefit analysis model. By including a declining seep flux capture rate we also incorporate the possibility of mechanically failure of the tents and infrastructure. The decline rate of 7.4 percent is considered the most likely because it is derived from the historical collection records of the ARCO seep tents.

Number of Tents

We evaluate gas capture, air quality impacts, and economic outcomes for projects with one to 20 tents.

Discount Rate

The discount rate is used to calculate the present value of all project values and costs, and to show those values summed over the project's 20-year life as one value in 2002 dollars. The model accepts any percentage rate, however three, five, and ten percent are used in project scenarios.

A value of five percent is chosen as an intermediate rate because the literature does not indicate which rate is appropriate for this project. *Cost-Benefit Analysis: Concepts and Practice* agrees that, "there is a lot of theoretical disagreement" (Boardman, 1996). However, this text suggests that a sensitivity analysis of the project costs and benefits to the discount rate should be completed to evaluate the options. The book continues, "Often, for example, the specified real (inflation-adjusted) discount rate is 10 percent. But many economists regard this rate as much

too high and advocate a lower rate" (Boardman, 1996). To illustrate the variation possible from different discount rates, a range of the project costs and benefits with discount rates ranging from no discounting to a 10 percent rate are given in the figure below.
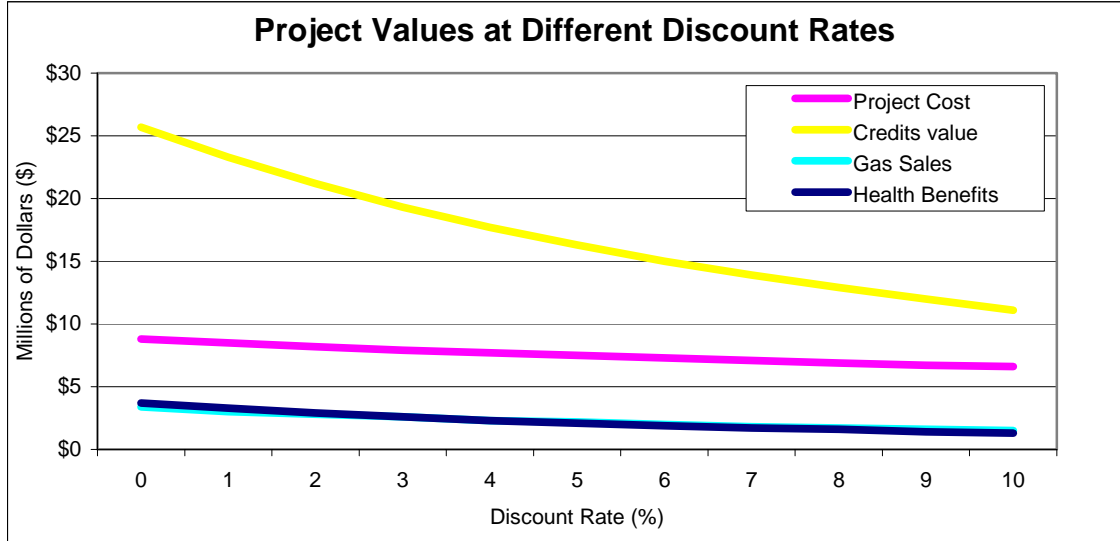
Figure 16. Value of most likely scenario project costs, emission reduction credits, revenues from gas sales, and health benefits discounted at rates of 0 to 10 percent.

Gas Sales Scenario

Again, four forecasts of natural gas pricing are used: Structural, Hotelling, Conservative ARIMA, and High ARIMA. Each of these models is described in the natural gas pricing section (5.2). Gas prices are valued to the present and then used to calculate the profitability of the project over its lifetime.

We consider the most likely forecast to be the conservative ARIMA. This forecast of natural gas prices is used because the pricing is at the lower end of the current structural model forecasts (see Section 5.2).

Health Benefit Scenario

Three scenarios are possible for health benefits: low, medium and high. The composition of each estimate is described in the health benefits section (5.3). The medium scenario is the most likely because it best estimates the sum of all the health benefits captured by this method. The low estimate is inferior because it does not include a value for reduction in mortality; the mortality study used in the low estimate predicted the coefficient relating ozone level to the change in health to be zero. This dramatically reduces the final benefits amount, and is not the best estimate considering that the other three of the four mortality effects studies reported a value. Conversely, the high estimate is an overstatement. The value of a statistical life used

for that estimate is $9 million, which is appropriate because it was derived from a study of respiratory illness. Nonetheless, it is too high of an estimate compared to commonly used values from economic literature. Therefore, the other estimate of the value of a statistical life ($1.5 M) is used in the medium estimate; it was derived from an assessment of low-level environmental risk, making it a more accurate estimate for this project.

Air Regime (NOx or ROG limited)

The options in this category are NOx limitation, ROG-limitation, or co-limitation (simulated by assuming one half of ROG ozone reduction) as defined in Section 3.8. Again, it is not certain whether Santa Barbara County is in a ROG-limited, NO_x-limited, or co-limited regime. Based on Figure 6, the estimate of Santa Barbara County NO_x and ROG emissions, the Santa Barbara airshed is in a NO_x-limited regime. However, this figure does not account for spatial and temporal variation within the air basin. Therefore, it is most accurate to assume that Santa Barbara is in a co-limited regime.

Emission Reduction Credits

When emission reduction credits are included in the analysis, the project's reduction in ROGs is calculated, and multiplied by the APCD's estimated value of $5,000 per ton of ROGs reduced, and then by the discount percentage (default is 80 percent) applied by the APCD (Allard, 2002). The discount percentage may also be varied in the model, and will be discussed in the sensitivity analysis. The SBCAPCD has indicated that it is unlikely that credits would be given for this project, thus they are not included in our most likely scenarios (Allard, 2002).

5.6 Most Likely Scenario

Most of the parameters of the model have several possible values one of which is more accurate or certain than the others, as described above. The scenario presented here uses all of the most likely parameter levels, listed in Table 14.

Table 14. Most likely project scenario parameter values and justification of why each is the most likely.

Input Parameter	Value	Justification
Starting Tent Flux Capture	220,000 MCF/tent/year	ARCO starting tent capture
Decrease in Flux Over Time	7.4%	Derived from ARCO tent decline in capture
Discount Rate	5%	Intermediate estimate
Gas Sales Scenario	Conservative	Current conservative estimate
Health Benefit Scenario	Medium (*50%)	Best valuation method
Air Regime (NOx or ROG limited)	Co-limited* (NOx-ROG)	Air model results
Emission Reduction Credits	No	SBAPCD judgement

Under these conditions the project's total value (dark blue line) and the profitability (pink line) become increasingly negative for additional tents (see Figure 17). The health benefits increase steadily for each tent added because the ozone production model assumes a co-limited air regime where each additional tent helps to reduce ROG emissions, in turn reducing ozone levels and improving air quality.
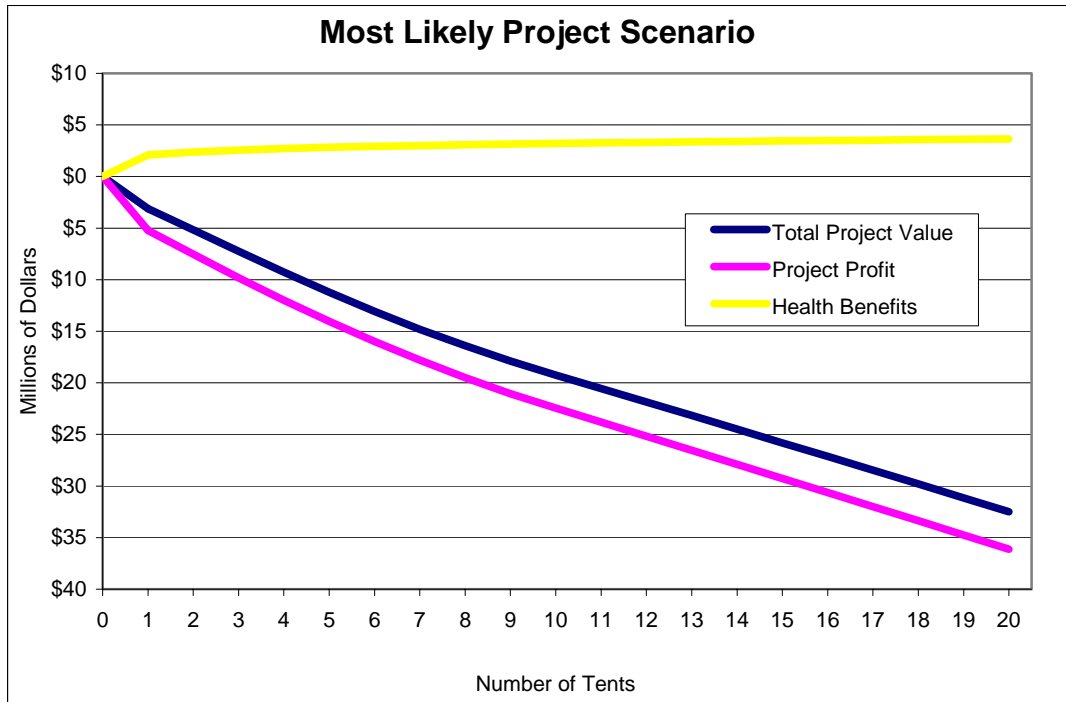

Figure 17. Most likely scenario results for tents 1-20.

One of the most important findings of this study is the negative project value and profit for this scenario. If even one tent were installed, the project would lose almost $5 million, which is not compensated by the $2 million in health benefits. Under

these conditions, which we find to be the most accurate and certain, we do not recommend installing tents over the Coal Oil Point seeps.

5.7 Sensitivity Analysis of Cost-Benefit Model

A sensitivity analysis is performed to quantify the model's sensitivity to change in each parameter. This analysis determines how high each isolated parameter has to be to make the project value positive and give the project a return on investment (ROI) of at least 10 percent (while other parameters are kept at most likely levels). This analysis focuses on the impacts of one parameter at a time; thus, all other parameters are at their most likely levels listed in Table X of the previous section. The 10 percent discounted return on investment is a standard listed in the COOGER study to evaluate oil development projects (COOGER, 2000). Please note that it is not a true accounting ratio for return on investment because taxes are not included. It is a ratio of profits to investment costs.

Sensitivity for each parameter is given below:

Starting Tent Flux Capture

We vary the tents' starting capture until a positive project value is achieved. Once the seep flux increases over 398,000 MCF/year (equivalent to ARCO tents' highest capture—in 1988), the total project value breaks even, and becomes positive (all other parameters are held at most likely levels). For the project to have a 10 percent ROI, the flux has to be at least 840,000 MCF/year. These fluxes are for the first tent that breaks even, and they would have to be sustained over a year for the positive (break even) values to continue. Further, they are for only one tent—additional tents increase the project cost and thus would require an even higher flux to break even. Given that the seepage varies dramatically, and the highest seep flux recorded under the existing seep tents was around 400,000 MCF/year, it is likely that the total project value breaks even in some years when there is abnormally high seepage. However, the 840,000 MCF/year seepage required for continued profitability seems extremely unlikely, as it has never been observed during the lifetime of the ARCO seep tents.

Decrease in Flux Over Time

In this analysis we vary the decline in seep flux over time from no decline to the 7.4 percent decline we statistically predict. As the seepage rate increases toward 100 percent (representing no seepage decline), the project value increases. However, even if there is no seepage decline, the project value and profitability are still negative. Again, this analysis is for only one tent, and further tents only decrease the project value and profitability.

Gas Sales Scenario

Four gas price forecasts are calculated as possible assumptions for the gas price parameter (most likely is "conservative" forecast); in the sensitivity analysis we test each forecast's effect on the project value. When the higher structural or hotelling gas pricing models are used, the total value and profitability of the project are higher but still do not break even. The high gas-pricing model is the only assumption that creates a positive value both for the total value and the profitability (for only one tent—all additional tents are less profitable). The integrated model is very sensitive to the gas pricing assumption; it is not surprising that gas pricing has such an impact, because revenue from gas sales is the major monetary return from this project.   This analysis shows that during years of sustained high gas prices, the project can be profitable. To achieve a return on investment of 10 percent, a price per MCF of at least $6.60 would be required for one tent, and further tents would require an even higher price. Although this high of a price is unlikely based on historical data, the price shock of 2000-2001 (annual average $12/MCF) suggests it may be possible.

Health Benefit Scenario

Since the most likely scenario assumes a medium health impact, the only alternative to increase revenues is to use the high health impact. There are only three levels of health impacts predicted—low, medium, and high—so the sensitivity analysis for this parameter can only measure the increase in the project value from medium to high health benefits. With high benefits, the optimum number of tents to install is two. It is important to remember that once the health benefits are high, the value of the project increases significantly, yet this increase is only in total project value, and so from an entrepreneur's point of view the profitability is still negative. The health benefits are the second most significant parameter in terms of the sensitivity of results.

 Air Regime (NOx or ROG limited)

The Santa Barbara airshed can be NOx limited, ROG limited, or somewhere in between the two—co-limited. The most likely scenario assumes that the Santa Barbara airshed is co-limited. If ROG limitation is selected, any change in atmospheric ROG inputs is assumed to reduce ozone concentrations. Under this scenario the health benefit is 100 percent of the medium value at just over $3.9 million, making the project value negative $1.3 million, and the optimum number of tents zero. The baseline scenario is already a high estimate because if we assume NO_x limitation, changes in ROG inputs to the atmosphere will not result in any ozone changes. The model reflects this, and so if we assume NO_x limitation rather than ROG limitation, the value decreases even further.

Ambient Ozone Concentration

The sensitivity of health benefit values to changes in the county's ambient ozone concentration is a linear function. Five ozone concentrations are chosen to represent county ozone levels (Table 15). A low concentration, 35 parts per billion (ppb), is chosen to represent the county at times of low concentration such as in winter months with little sunlight. A medium value of 63 ppb is chosen based on the average ozone concentrations of county stations on 1999, 2000, and 2001 exceedance days. Federal and state standards of 85 ppb (federal 8-hour), 95 ppb (state 1-hour), and 120 ppb (federal 1-hour) are also evaluated. As ozone concentration increases, the health benefits increase due to reducing the same 0.4 percent of a higher ambient level of ozone in ppb.

Table 15. Health benefit from most likely scenario air quality improvement for five levels of ambient ozone concentration (in dollars).

Ozone (ppb)	Medium Health Benefit ($)
35	$3,900,000
63	$7,100,000
85	$9,500,000
95	$10,700,000
125	$14,000,000

Emission Reduction Credits

The model options for this parameter are whether or not they will be acquired, and if so, what percentage of captured ROGs will transfer as ROGs that receive credits. Issuance of ERC determines the overall fate of the project more than any other parameter used in this model. If they are acquired, both the total value and the profitability of the project increase by more than $30 million for the initial tent; but, without ERC the project does not break even given our most likely scenario assumptions. If credits are given, a minimum transfer of 15 percent is required to give the first tent a 10 percent return on investment (again, additional tents are less optimum). A 15 percent transfer means that 6.6 tons of ROGs would have to be reduced to acquire one of ROGs reduction credits.

5.8 Cost-Benefit Analysis Model Scenario Results

As many of the parameter values are uncertain, it is useful to test several scenarios other than the most likely one presented above. The sensitivity analysis of the model to individual parameters described in Section 5.7 shows that acquisition of emission reduction credits is the only individual parameter that affects the final project decision. It is also instructive, however, to test the model's prediction of scenarios that have different combinations of parameter values. For each of the six alternate

scenarios presented below we define an optimal number of tents to install (including the margin by which that number is optimal), and the associated value and profit.

Before we present the scenarios, however, it is illustrative to test the model by evaluating its upper and lower bounds. The most optimistic values for each of the integrated model's parameters are: a starting flux equal to the ARCO tents' highest capture, no decline in flux over time, a discount rate of three percent, a high scenario for natural gas pricing, high assumptions for health benefits valuation, and the assumption that emission reduction credits will be acquired. In addition, the county is assumed to be ROG-limited allowing for the highest level of ozone production. These assumptions are not realistic, but their use in the model is illustrative to show the model's potential and also the care that must be used in defining assumptions. From a social planner's point of view including both health benefits and emission reduction credits counts the same reduction in air pollution benefit twice. Table 16 shows project value, profit, and rate of return for several numbers of tents in this high-parameter example.

Table 16. Model results with most optimistic parameters (1-20 tents). Project Net Value and Profit are rounded to the nearest million.

Number of tents	Net Value (Millions)	Profit (Millions)	Return on Investment (%)
1	$225	$144	1840
5	$296	$186	1057
10	$329	$205	769
15	$350	$216	636
20	$363	$222	539

A similar illustration is achieved by running the model with each of the least optimistic parameters: a starting flux equal to what the Venoco tents now capture, a decline in flux over time, a discount rate of 10 percent, a conservative scenario for gas pricing, conservative assumptions for health benefits valuation, the assumption that the county is NOx limited in its ozone production, and that no credits will be given. The result is a project cost of more than five million dollars greater than expected revenues. However, this scenario is more probable, and closer to the most-likely scenario.

The remainder of this section explains and illustrates the results for six important scenarios. All the parameters that are changed are more optimistic than or equal to the most likely scenario. The scenarios and their results presented below represent optimistic parameter assumptions, and should be interpreted accordingly.

These hypothetical scenarios are all based on variations of one or more of the most likely scenario's parameters; changes to each scenario are made so that the cumulative effect of each additional parameter is shown. Most likely scenario parameters are listed in Table 17 below and illustrated in
Figure 17. The six alternate scenarios are shown in Table 17.

Table 17. Definition of potential seep tents project scenarios.

| Parameter | Most-Likely | Alternative Scenarios | | | | | |
		1	2	3	4	5	6
Scenario Description	Most-likely	ROG limitation	High Gas Pricing	High Gas Pricing/ Health Benefits	ERC	Hotelling Gas Pricing	No Piping Costs
Starting Tent Flux Capture (MCF/tent/yr)	220,000	220,000	220,000	220,000	220,000	220,000	220,000
Decrease in Flux Over Time	7.4 %	7.4 %	7.4 %	7.4 %	7.4%	7.4 %	7.4%
Discount Rate	5%	5%	5%	5 %	5%	5%	5%
Gas Sales Scenario	Conserv-ative	Conserv-ative	High	High	Conserv-ative	Hotelling	Conserv-ative
Health Benefit Scenario	Medium	Medium	Medium	High	Medium	Medium	Medium
Air Regime (NOx or ROG limited)	Co-limited	ROG-limited	ROG-limited	ROG-limited	Co-limited	Co-limited	Co-limited
Emission Reduction Credits	No	No	No	No	Yes (80%)	No	Yes (5%)

Each of the six scenarios represents an important aspect of our findings. In scenario one the air regime is fully ROG limited instead of co-limited, doubling the ozone reduction from each hypothetical tent and as a result doubling the health benefits. Scenario two additionally tests the result of increasing gas pricing to a high yet stable price of $6.10 per MCF per year. Scenario three builds further on scenario two by increasing the health valuation to High, making this scenario the most optimistic estimation of the parameters among the six scenarios. For scenario four, all parameters are returned to their most likely levels, except that we assume emission reduction credits are acquired for the project. Scenario five incorporates the Hotelling method of natural gas pricing. This parameter change is included because it is a classic theory on natural resource valuation that takes into account the non-renewable supply of a natural resource such as natural gas. It proposes that because the total stock of the resource diminishes as it is used, its value increases at the rate of return because it is becoming scarcer. Scenario six illustrates the possibility of lower project costs due to not installing pipeline. If the tents are able to connect to the piping infrastructure for platform Holly, then the project costs are reduced by $3.8 million.

The outputs of the model for each scenario are: the optimal number of tents, project value, health benefit value, and project profit, as shown in Table 18. If the optimal

number of tents under a scenario is zero, no tents should be installed; for those scenarios the values for one tent are given in parentheses.

Table 18. Summary of results: optimal number of tents, project value, health benefit, and project profit for the most likely and six alternate project scenarios.

Scenario	Description	Optimal Tents	Project Value	Health Benefit	Project Profit
Most-likely	Most-likely	0	$0	$0	$0
		(1)	(-$3.1)	(+$2.1)	(-$5.2)
1	ROG-limitation	0	$0	$0	$0
		(1)	(-$1)	(+$4.2)	(-$5.2)
2	High Gas Pricing	1	$4.3	$4.2	$0.1
3	High Gas Pricing/ Health Benefits	5	$41.3	$48.2	-$6.9
4	ERC	3	$32.6	$2.6	$30
5	Hotelling Gas Pricing	1	$0.2	$2.1	-$1.9
6	No Piping Costs	1	$2.4	$2.1	$0.3

Results from these six scenarios show important points to evaluate in any seep tents project. Scenario one shows that even if the Santa Barbara airshed is found to have fully ROG-limited ozone production, a seep tents installation project would not be valuable or profitable. Scenario two builds on that finding by adding high natural gas pricing thus shifting the value of the project for one tent up to $4.3 million, and making the profit just greater than $100,000. Under this scenario the optimum number of tents is one; the value and profit drop as the number of tents increase. As with all scenarios, the health benefits are always positive and increase almost linearly with the number of tents. Scenario three builds upon scenario two by adding high health benefits valuation, increasing the overall value of the project by more than $35 million. With high health benefits, the shape of the project value curve changes from steadily decreasing to concave with a peak at the optimum number of tents. This peak for scenario three is at five tents, with a corresponding project value of about $41 million. Yet the project profit curve retains the negative slope because profits are independent of health benefits.
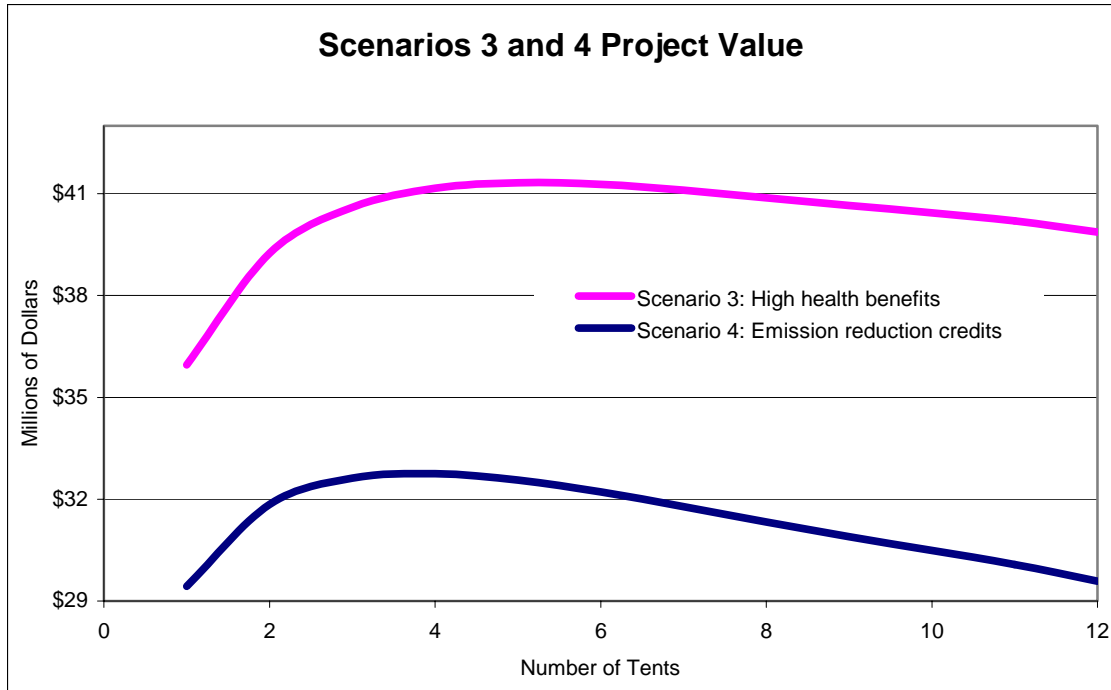
Figure 18: Project value of Scenarios 3 and 4.

Scenario four shows that the issuance of emission reduction credits (ERC) dominates the project's value. If ERC are issued, even when all other parameters are still at their most likely values, the total project value and profitability both increase by more than $30 million. Similar to adding high health impacts, issuing ERC changes the shape of the value curve as shown in Figure 18, and now also the profit curve from having a negative slope to concave and peaking at three tents. The optimal number of tents to install under these assumptions would be 3, at a project value of $32.6 million and profit of $30 million. From an entrepreneur's point of view, the optimal number of tents to install in scenario four is the same as the previous scenario that did not include high health benefits. Even under the constantly increasing prices of the Hotelling gas-pricing scheme in scenario five, the project does not become profitable. The scenario only has a positive project value due to the value of health benefits. The increase in gas prices is not enough to compensate for project costs. The Hotelling pricing scheme is unlikely, however, because a seep tents project could not capture enough natural gas to affect the market in California and thus the gas pricing.

Scenario six provides an example how a policy could be designed to motivate installing seep tents if a potential project's value (health and other benefits) were positive. Emission reduction credits could be issued to compensate an entrepreneur for their losses and create a profit incentive for them to execute the project. In scenario six, the project loses $1.7 million (without credits). For a credit of only 5% of this project's ROG reduction (the 1982 ARCO project used 80%), the owners of the tents would be compensated $2 million for this loss and would achieve an

industry standard 10% rate of return. This suggests that a policymaker could create an incentive to produce an air quality improvement valued at $2.1 million for $2 million in emission reduction credits.

The results of scenarios one through six indicate the strong influence of parameters like health benefits and emission reduction credits (ERC), as well as their cumulative interaction. These results show that the health benefits have a greater impact than gas pricing on the project value, but not profits. Though the health benefits are quantified in this study, they are external benefits whose dollar values are not realized by either the business that undertakes the project or county residents who benefit from improved air quality. For a business to undertake seep tent installation, the project would have to be profitable. Emission reduction credits, therefore, have more of an impact on the decision to install seep tents than any other parameter.

One of the most important findings of this study is that a policymaker should weigh health benefits against emission reduction credits. A seep tents project would not be profitable without emission reduction credits, and so a policymaker would have to decide if the potential health and other benefits from such a project merit the credits. In this case, the policymaker's question is what level of emission reduction credits would have to be issued to compensate the entrepreneur for the remainder of the project costs and is the value of those credits commensurate with the health benefits from the project? However, the cost effectiveness of this method should be compared to others that are available. The following section will provide examples of these comparisons.

5.9 Cost-Effectiveness of Seep Tents

When making air pollution prevention policy, the costs of different strategies should be compared to reach a cost-effective solution. If the SBCAPCD considers subsidizing seep capture tents as a method of air pollution prevention by issuing emission reduction credits, then the agency should compare the costs of the credits to the costs of other abatement technologies. For example, ozone reduction is subsidized by the retiring of old cars (RECLAIM program, Los Angeles County, CA). Below, we compare the average costs of reducing ROG and methane emissions with seep tents to other abatement technologies. Average costs are the project cost less gas sales revenue (under most likely scenario parameters) per tent for a specific number of tents installed. We numerically deduce these costs from the data produced by the model (see Appendix D).

5.9.1 Cost of Ozone Abatement

The goal of installing seep tents for pollution control is to reduce ozone formation in the county. Cost comparisons are not typically made for ozone reduction, but for its precursors, NOx and ROGs. However, we calculate the average cost of ozone abatement using seep tents to allow for future cost comparison (see Appendix D). This calculation is also important because it illustrates the cost of reducing the criteria

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pollutant rather than its reactants and identifies the difficulty of relating abatement costs to ozone production because of its complexity. Table 19 describes the average cost of ozone abatement for several numbers of tents. For the first tent the average cost of ozone abatement is about $2,000 per ton of ozone reduction over 20 years. The average costs increase as the number of tents increase.

Table 19. Average cost of ozone abatement in dollars per ton over 20 years.

Tent	Average cost of ozone abatement ($/ton)
1	$3,300
5	$6,600
10	$9,200
20	$13,000

5.9.2 Cost of ROG Reduction

Though the policy goal of a seep tents project would be to reduce ozone air pollution, ROGs are the actual emission reduced and thus more commonly measured and compared. To compare the cost of ROG emission reduction by capping natural seeps to other abatement technologies, we calculate the average cost of ROG emissions reduction per ton (Figure 19).
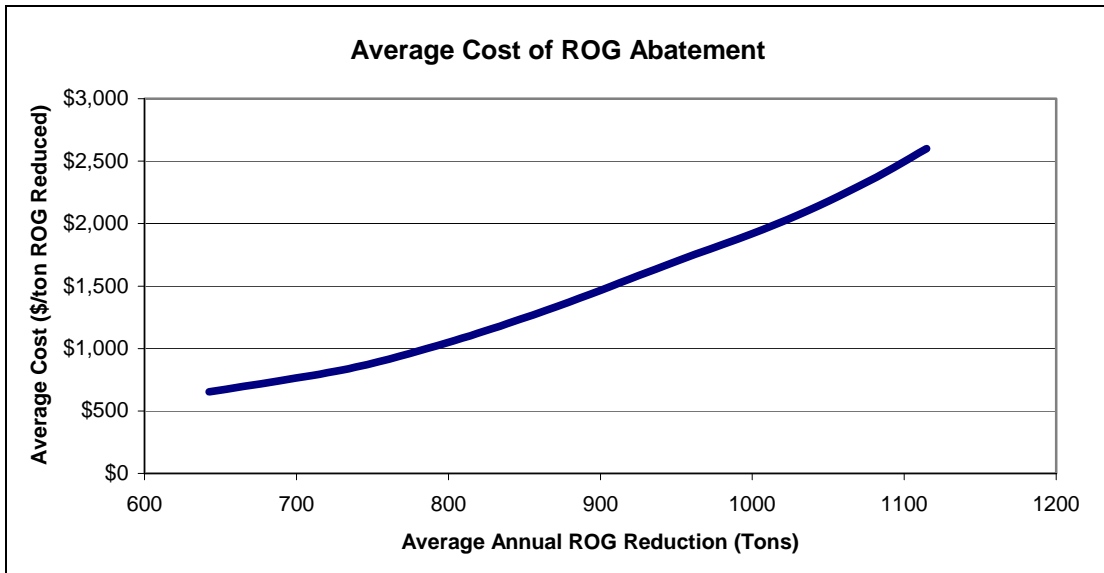

Figure 19. Average cost of ROG emission reduction for 1 to 20 tents.

The average cost of ROG emissions reduction using seep tents ranges from $650 to $2,600 per ton. For comparison, Table 20 shows the costs of two alternative abatement policies.

Table 20. Estimates of ROG reduction costs from methods of air pollution prevention other than seep tents.

Description	Target Emission	Cost ($/ton reduced)
Mobile source emission reduction credits: accelerated retirement of pre-1972 cars (CARB-2, 2002).	ROG Credits ($800/car)	4,700
Cost effective threshold (annual cost/ton of controlling) (San Joaquin Valley Unified Air Pollution Control District, 2002).	VOC	5,000

Table 20 summarizes cost estimates for other methods of ROG emission prevention. These estimates range from $4,700 to $5,000 per ton of ROG reduction; furthermore, they suggest that it may be cost-effective to reduce ROG emissions via seep capture tents.

5.9.3 Value of Methane Emission Reduction

Seep tents would reduce emissions of the greenhouse gas methane in addition to lessening ozone air pollution through reducing ROG emissions. Two calculations are made regarding the cost effectiveness of seep tents in reducing methane emissions: the average cost per ton of methane emissions reduced, and the value per ton of that emission reduction in terms of tradable emission reduction credits. The average cost of methane reduction is shown in Table 21. If one seep tent is installed, our calculations indicate that an average of 1912 metric tons of methane will be captured annually.

Table 21. Average cost of methane emission reduction.

Number of Tents	Average Cost of Methane Reduction ($/Ton)
1	$200
5	$400
10	$560
20	$800

Emission reduction trading values are shown in Table 22 for both carbon dioxide and methane. These values are based on worldwide emission trading data and the Greenhouse Gas Emissions Reduction Trading (GERT) Pilot project in Canada (for a full summary please see Appendix D). Values of carbon dioxide trading costs range from $1.33 to $22.00 per metric ton with common estimates ranging from $2.50 to $6.00 per metric ton. Methane emissions trade for $3.80 to $4.33. It should be noted that transaction costs are not included in these prices.

Table 22. Common cost estimates of emissions trading for 1 metric ton of greenhouse gas.

Cost (per metric ton)	Greenhouse Gas	
	Carbon Dioxide	Methane
Low	$2.50	$3.80
High	$6.00	$4.33

The tables above show that the seep tents' average cost of $200 to $800 per ton (for a 1 tent project) to abate methane emissions is much higher than the average value of $3.80 per ton on the global emissions reduction credit trading market.

Table 22 also implies that control technology costs for methane and carbon dioxide are similar because the values of traded emissions reduction are close. As discussed in Chapter 3, the Global Warming Potential (GWP) for methane in the atmosphere is about 25 times greater than carbon dioxide over a life of 100 years, and 62 times greater then carbon dioxide over a life of 20 years. Using a range of estimates we demonstrate that generating the same reduction in global warming by removing methane would cost 0.6 to 1.5 percent of removing the same GWP in carbon dioxide (see Appendix D and E for calculations). Reducing the global warming impact via methane removal could be 400 times more effective per dollar compared with carbon dioxide removal.

We also calculate the total value of methane reduction by seep tents. Figure **20** shows the potential emissions trading value of the methane captured to be from approximately $7,200 to $8,200 per year, and $145,000 to $165,000 for the 20-year horizon of a one-tent project. The range of values based on the globally traded permits for a 20-tent project is $252,000 to $287,000 over a 20-year period. This value is not enough to outweigh the costs of methane reduction, or to make the most likely seep tents scenario valuable.
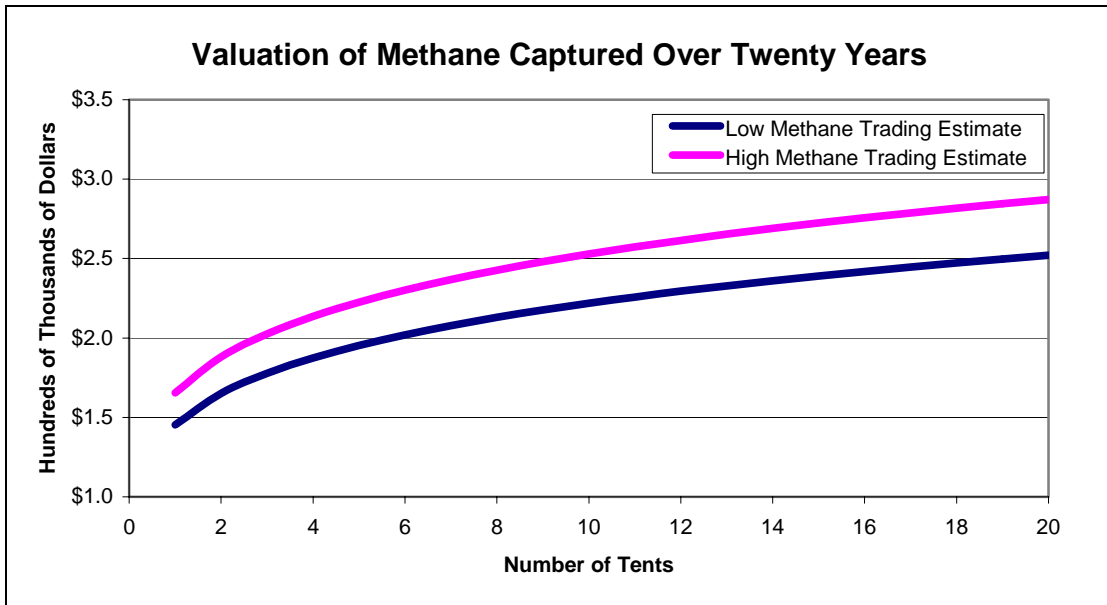
Valuation of Methane Captured Over Twenty Years

Figure 20. Emissions trading valuation for methane captured over twenty years for 1 to 20 tents.

The results of this methane valuation have several caveats. First, we assume that 87 percent of the methane is captured on the sea floor by a seep capture tent, which may be an overestimate (as discussed in Chapter 3). Second, if the methane were used in electric power generation, it would be transformed to carbon dioxide, another greenhouse gas. Thus, if methane emissions reductions credits were acquired in a global market, policymakers could require a transfer ratio similar to ROG credit issuance, significantly reducing the credits' value. This taken into account, even if methane emission reduction tradable permits were instituted in the U.S., they would not outweigh the likely project loss of $3 to $5 million.

In conclusion, seep tents may be a cost-effective means to reduce ROG emissions as compared to reducing vehicle emissions. However, a policymaker should also compare the cost effectiveness of seep tents in achieving the goal of reducing ozone air pollution. Methane emission reduction by seep tents can be valued using global emissions trading data, yet this value is not great enough to make the most likely project scenario profitable.

5.10 Conclusions

Throughout this section, the viewpoints of the entrepreneur and of the policymaker are taken when evaluating the economic results. A conceptual model determines the project value by summing the revenues from natural gas sales, the value of health benefits from reduced ozone, the value of emission reduction credits, and the capital, installation, and maintenance costs. Of the four methods of natural gas price forecasting used, the most conservative is the most likely. The monetized non-market value of health benefits from ozone reduction is determined from economic literature, and a likely scenario is identified. In this scenario probabilities are determined for the

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incidence reduction in 11 illness categories, yet only one predicts a reduction in actual cases of the illness per year (two cases of acute respiratory illness). These results are integrated into a cost-benefit analysis model to evaluate project scenarios.

The integrated model is a strong tool that can evaluate over 17,000 defined scenarios to produce decision-making results. The parameters of the model are:

Fixed parameters
- Seep field flux
- Capital and design costs
- Piping installment costs
- Maintenance costs
- Average ambient ozone in S.B. County

Variable parameters
- Flux captured by the new tents
- Temporal decline in seepage
- Number of tents
- Discount rate
- Gas sales scenario
- Health benefits scenario
- Ozone production regime
- Emission reduction credits

Many hypothetical project scenarios are simulated that reinforce the importance of health benefits and credits. The most likely project scenario is defined, which results in a negative project value and profit. A sensitivity analysis of the project value and profit to each model parameter is conducted, finding that health benefits and emission reduction credits are the model's most influential parameters. Of the five additional scenarios tested, two result in no seep tent installation, one suggests that one tent should be installed, and the scenarios with high health benefits and emission reduction credits report that five and three tents are optimal, respectively.

Under likely project conditions, installing new seep tents is not practical from either a social (public policy) or an entrepreneurial viewpoint. However, the model also shows that acquisition of emission reduction credits is the most important factor in the project's economic practicality.

While evaluating the most likely project parameters and resulting scenario, an important comparison between the value of emission reduction credits and health benefits is brought to light. Theoretically, emission reduction credits capture the benefit to society of improved air quality. They are a means to reimburse a private party for their cost in creating a benefit to society. Thus, credits are income to an entrepreneur, but can be cost to society if incorrectly estimated. If the benefit is correctly valued, then the emission reduction credits should be nearly equal to the benefits worth to society. In that sense both parties' gains are equal. However, if the

benefit is undervalued, the credits will not fully reimburse the business for its contribution to society. Similarly, if the benefit is overestimated, the credits will cost society more than the benefit is worth. This overestimate is the case we have discovered with the seep tents project.

The discrepancy between credits and health benefits is clear from our cost-benefit model's outputs. Our most likely scenario gives a range of emission reduction credit awards and health benefits shown in Table 23.

Table 23. Value of credits and health benefits for 1, 10, and 20 tents.

Number of Tents	Emission Reduction Credits (millions of dollars)	Health Benefits (millions of dollars)
1	32.5	2.1
10	49.7	3.2
20	56.5	3.6

The important finding is that the value of credits is more than an order of magnitude greater than the most likely value for health benefits from the same reduction in ozone. An obvious response is that the high health benefits valuation scheme is similar to the value of credits; however, remember that the high valuation derives most of its value from the $9 M value of a statistical life in mortality reduction calculations. The reduction in mortality is only a seven percent chance for one incidence, and further, the value of $9 M for a statistical life is higher than average figures. The credits capture benefits other than just health improvements—they also include the value of reduction in agricultural or structural damages from ozone. Although they are not estimated in this study, these additional benefits would not exceed the health benefits. If issued, the ERCs should be the same order of magnitude of the health benefits.

The discrepancy between health benefits and emission reduction credits can also be corrected by critically comparing the two values. Currently, the credits are expected to transfer from ROGs reduced to ROGs eligible for credits at a rate of 80 percent. For the value of credits and value of health benefits to be equivalent, this transfer rate should be five percent. For the most likely project, a five percent transfer rate does not make the project valuable or profitable for any number of tents, indicating that the health benefits do not outweigh the project's economic loss. An alternate solution would be to change the dollar value of one credit instead of the transfer percentage.

Further analysis of the most likely project scenario is done to find the average cost of ozone abatement, ROG emission reduction, and methane emission reduction using seep capture tents, and the value of methane emission reduction using global market-based trading permits. The average cost ranges between $3,000 and $13,000 per metric ton of ozone emission reduction. The average costs of ROG emissions reduction using seep capture tents ranges from $650 to $2,600 per ton. The average costs of methane emissions reduction using seep capture tents ranges from $200 to

$800 per ton. The potential emissions trading value of the methane captured is valued to be approximately $7,200 to $8,200 per year, or $145,000 to $165,000 of a one-tent project and $252,000 to $287,000 for a twenty-tent project for a twenty-year time horizon. All of these figures can be compared to other means of achieving the same goal to reach a cost-effective decision.

Chapter 6: Discussion and Recommendations

6.1 Discussion and Conclusion

This report addresses the question of whether installing additional seep capture tents would be environmentally advantageous, politically feasible, and economically practical. Our approach involves integrating economic, statistical, and air quality models with an analysis of current legal, political and biological conditions. An integrated analytical model is used to simulate project scenarios and conclude which conditions would be necessary for the project to be valuable to society and profitable to an entrepreneur. In Chapter 1 we summarize the history of seep tent installation by ARCO Oil and Gas Company in 1982. In Chapters 2 and 3 we show that a seep tents project would likely have a minimal long-term impact on water quality and marine ecosystems, but a slight improvement in air quality. Given this finding, we move to the second half of our research question to address the feasibility of this project in Chapters 4 and 5. Chapter 4 explains the several regulatory obstacles for this unusual project. Chapter 5 presents the costs and benefits of installing seep tents, and how each of those values is determined. In this chapter we outline in detail the key findings of each previous section, concluding with the economic criteria necessary for a seep tents project to be practical. The final section of the study presents recommendations based on each of these findings.

Environmental Impact

In Chapter two we show no benefits, and undetectable impacts on the water quality and marine ecology from installing additional seep tents off Coal Oil Point. Specifically we find that:

- Coal Oil Point Seeps release several hydrocarbon compounds into the ocean, approximately 87 percent of which is methane.
- Most of the released hydrocarbons dissolve, disperse and/or biodegrade before they have a detectable impact on water quality and marine ecosystems.
- A unique benthic community is adapted to the seep sediments. Toxicity-tolerant bacteria decompose and use seep hydrocarbons to increase their biomass. The hydrocarbons then enter the food chain through organisms that prey on the bacteria, increasing the biomass of the seep community.
- Most impacts associated with tent installation will be short term, one-time impacts to the seafloor communities. Laying pipeline could cause long-term ecosystem level impacts if the piping is not placed sufficiently far from critical habitats like kelp beds.
- The impact on the marine ecology is not well characterized due to a lack of appropriate studies, and thus could be larger than estimated in our study.

Additionally, we find a slight improvement in air quality from tenting the Coal Oil Point seeps. The important information from Chapter three includes:

- Some of the hydrocarbons released by the seeps into the atmosphere are reactive organic gases (ROGs).
- Tropospheric ozone (smog) is formed by the interaction of NO_x, ROG's, and sunlight, and is a serious health concern.
- Methane, the primary component of seep gas, is a potent global warming agent. However, methane emissions from the seeps account for less than 0.004 percent of global emissions.
- Seeps contribute to ozone formation, yet this contribution is small compared to anthropogenic sources. The magnitude of the seeps' contribution to ozone production depends on the chemistry of Santa Barbara's airshed, and can vary considerably.
- Depending on the following airshed chemistry options, the reduction in ROGs from additional seep tents would:

Air Regime	Effect of Seep Tents on Ozone Production
ROG-limited	Reduction
NO_x-limited	No effect
Co-limited	Some reduction

  Preliminary analysis in this study suggests the possibility that the airshed is NOx limited. Most likely, Santa Barbara County varies between NO_x limitation and NO_x-ROG co-limitation. Results of this study also suggest that the ROGs produced by the seeps are less reactive than the other hydrocarbon emissions in the County, and thus emission reductions due to seep capture are not as effective as a simple analysis of total tonage of ROGs would suggest. However, the chemistry of ozone production is not linear, making this determination difficult.
- Our analysis indicates that the first new seep tent would reduce about 0.4% of total ozone produced in Santa Barbara county, averaged over 20 years. Each additional tent will reduce less ozone than the previous one. For example two tents is estimated to reduce only about 0.5% of the county's ozone production.

Given these findings, capping seep ROG emissions is expected to reduce about 0.4-0.8 percent of the total ozone production in Santa Barbara County, depending on how many tents are installed. However, it is important to remember that this percent reduction depends on other sources of ozone production such as motor vehicles, industrial and natural sources. More specifically, if one of the sources, such as total motor vehicle emissions increases, the relative reduction due to proposed seep tents will decrease even further. Given that Santa Barbara County is projected to have increased population, we can expect the motor vehicle traffic and total motor vehicle NO_x emissions to increase. As a result, the relative reduction in ozone production due to the seep tents will fall below the estimated range of 0.4-0.8 percent. Depending on the specific criteria or measures used (e.g. health benefits, cost effectiveness) the significance of this reduction will change. There are large uncertainties, both in the

data and the model used in this analysis such that the numerical results and their significance must consider these limitations.

Regulatory and Economic Feasibility

In light of the previous chapters' finding of little environmental impact but a potential air quality improvement, the key questions become whether seep tent installation is possible given the regulatory obstacles, and practical given the expense for an engineering project of this magnitude. Specifically, do the benefits of improved air quality outweigh the costs of designing and installing additional tents?

Beyond the permits and approval required from the California EPA, Army Corps of Engineers, State Lands Commission, Coast Guard, Minerals Management Service, S.B. County Planning and Development, and S.B. County Air Pollution Control District to install seep capture tents in the Santa Barbara Channel, there are several regulatory complications that need to be considered regarding processing and refining the seep gas. Processing the gas will most likely require an onshore facility—an important regulatory obstacle. Further considerations include:

- Current regulations under the Santa Barbara Coastal Plan limit the likelihood that seep gas is sent to a newly built onshore processing facility. The regulations in Coastal Act section 30263 imply that new facilities will not be developed unless existing facilities are used at maximum capacity. Furthermore, Measure A96 would be a potential obstacle because the project will be dependent on the county voters for approval of such a facility.
- If the seep gas were sent to an existing onshore processing facility, it would most likely be the Ellwood Oil and Gas Processing Facility. The gas captured by the existing tents is already processed there, and it is the closest onshore support facility to the seep field. The Ellwood facility is currently under-utilized, but is designated as a non-conforming land use because the zoning of the facility changed from industrial to residential. This means that no additional gas can be processed at that facility. It is not clear from the legal language if this prohibition refers to the design or the permit capacity.
- It is unlikely that the project will receive emission reduction credits (ERC) for two primary reasons:
  1. An applicant must show the reductions are permanent, yet the seepage varies over space and time.
  2. As a natural emitter of ROG's seeps are not listed as a polluting source, and thus are not eligible for credits.
  Credits are also contingent on whether Santa Barbara County is in non-attainment for ozone. Currently the county is in attainment of only federal ozone standards. Given these factors, it would be a rare exception to issue credits for a seep tents project.

In light of the above points, the two central legal uncertainties are those associated with an onshore processing facility and the issuance of emission reduction credits

(ERC). Additional uncertainty over ERC is added since the air regime is not known well enough to confidently quantify the contribution of the seeps to ozone production.

Even though there are several regulatory obstacles to a seep tents project, the project's value, specifically in terms of air quality improvement, should be determined. Two views are taken in evaluating the economic results: that of the entrepreneur and that of the policymaker. The entrepreneur needs to know the project profit, which is the sum of revenues from natural gas sales, the value of emission reduction credits, and the capital, installation, and maintenance costs. Of primary interest to the policymaker is a comparison of the project's value—namely the health benefits from reduced ozone—compared the amount of emission reduction credits that would have to be issued to make the project profitable. This comparison is conducted below, following a brief description of the components of the project's profit and value:

- Four methods of forecasting natural gas prices are determined: Conservative ARIMA, High ARIMA, Hotelling, and Structural. The most likely of these is the Conservative ARIMA.
- The value of improved health from ozone reduction is determined using a range of studies from the economic literature, and results in three scenarios: low, medium, and high. The most likely valuation scenario is medium.
- The health benefit analysis predicts a reduction in the probability of respiratory illness incidences. However, only one of the 11 categories (acute respiratory symptoms) shows an actual reduction of illness (2 cases reduced per year).

In addition, an integrated cost-benefit analysis model is developed to evaluate hypothetical project scenarios, with the following results:

- The cost-benefit analysis model is used to analyze over 17,000 defined project scenarios. The model has virtually unlimited ability to create additional scenarios.
- The model's fixed parameters are seep field flux, capital and design costs, piping installment costs, maintenance costs, and average ambient ozone in S.B. County. The variable parameters are: flux captured by the new tents, temporal decline in seepage, number of tents, discount rate, gas sales scenario, health benefits scenario, ozone production regime, and emission reduction credits.
- A "most likely scenario" is defined; this scenario has a negative project value and profit.
- The sensitivity of the project value and profit to each model parameter is tested; health benefits and emission reduction credits are the most influential parameters.
- Of the five other scenarios tested, one with ROG-limitation results in no seep tent installation, the two with High or Hotelling gas pricing suggest that one tent should be installed, and the scenarios with high health benefits and

emission reduction credits report that five and three tents are optimal, respectively. We find that while the health benefits parameter makes the project valuable, only emission reduction credits make it profitable.

Under likely project conditions, installing new seep tents is not practical from either a social (public policy) or an entrepreneurial viewpoint. From a business' point of view, unless emission reduction credits are issued or unlikely high market gas pricing conditions are sustained, the project will not be attractive. From society's point of view, the most likely scenario does not have a positive value because society's benefits are still less than costs to the private firm. Of course, this conclusion depends on the valuation assumptions and model parameters. Importantly, the model also shows that emission reduction credits and valuation of health benefits are the most determining factors in a project's economic practicality. Based on the discussion of health impacts and emission reduction credits, from a policymaker's point of view, only one should be included in the total value of the project because including both counts the same external benefits twice.

One of the most important findings of this study is that a policymaker should compare the values of health benefits and emission reduction credits. Under the most likely health valuation approach, the benefit from reducing ozone with seep tents is $2.1 million. In a seep tents project, credits would reimburse the owners of the tents for generating an air pollution reduction that is costly to them, but valuable to Santa Barbara residents. To create emission reduction credits with a comparable value to the health benefits, a 5% transfer ratio of credited to captured hydrocarbons would be required.

If the goal of a project is to reduce ground-level ozone, the figures for our most likely project scenario may be compared to other abatement technology to reach a cost-effective decision. Results suggest that seep tents are:
- Cost effective for ROG abatement
    - $650 to $2,600 per ton with seep tents vs. $4,700 to $5,000 per ton using other abatement technologies (RECLAIM)
- Not cost effective to abate methane emissions
    - $200 to $800 per ton with seep tents vs. $3.80 per ton on the global trading market (Canada's pilot program).

Additionally, we show that to reduce one ton of ozone using seep tents would cost between $3,300 to $13,000 over 20 years.

In conclusion, we find that a comparison should be done between the value of health and other benefits from improved air quality in Santa Barbara County and the costs of a seep capture tent project. If emission reduction credits within the amount of this benefit make the project profitable when it previously was not, then a regulator can generate an incentive for a private party to create an improvement in air quality that benefits society. However, the cost-effectiveness of this method—creating an incentive to install seep capture tents that reduce precursors to ozone—should be

compared to others (mobile source emission reductions, scrubbers) that are available so that the optimal one is chosen.

6.2 Recommendations

Based on the findings in this study, we are in a position to make several recommendations. However, the results of this study are limited by the available data and uncertainty. More information regarding the Coal Oil Point seeps, Santa Barbara airshed chemistry, tent design, and permit conditions would improve the robustness of the results of our study. While the exact results provided by the model are limited by the assumptions made, the model methodology provides a conceptual and analytical tool for evaluating the feasibility of installing seep capture tents and similar projects in order to make well-informed and comprehensive decisions. We recommend:

- Research to determine whether the county airshed is ROG, NO_x, or co-limited. Overall, better understanding the chemistry of the airshed is required for evaluating the specific air quality benefits from the introduction of seep tents.
- Use of Santa Barbara County hospital data to derive the exact relationship between illness and ozone instead of a benefits transfer method that calculates the value for Santa Barbara based on hospital data from other cities.

If a seep tents project is proposed in the future, we recommend that the following be considered by an entrepreneur:

- The exact permitting associated with onshore gas processing. The absence of an allowable onshore processing facility for the gas could pose a serious obstacle for this project, thus this issue should be determined before costly engineering studies are contracted.
- Similarly, before any expenditure on the project, the acquisition of emission reduction credits should be verified. The project is highly unlikely to be profitable without credits.
- If the above two points are resolved and the project begins, we strongly recommend conducting a detailed ocean bottom survey of the Coal Oil Point seep field to map the highest areas of seepage more accurately. This information is critical in deciding the optimal location of the tents. If the tents are designed to be movable, this survey should be repeated before selecting new sites.

A policymaker should also evaluate the following in light of a new seep tents project:

- Calculate the precise amount of ozone reduced by seep tents if they are installed. This must be determined for the health benefits valuation and emission reduction credit amounts to be accurate.

- Permit conditions should account for the seeps' spatial and temporal variability. They should include built-in monitoring requirements to assess the actual reduction in ROG's captured to prevent possible over or under estimates of health benefits. This would ensure that the contribution, if any, of seep tents in reducing ozone is quantified correctly.
- A socially responsible value for the credits that is equal to or less than the health and other possible external benefits of ozone reduction by seep tents.
- The cost effectiveness of seep tents compared with other methods of reducing tropospheric ozone (smog).

Improving air quality by reducing tropospheric ozone and at the same time producing natural gas as an energy source by capping the seeps off Coal Oil Point is a fascinating idea. Yet the project's attractiveness depends on the many factors estimated in this study. We find that under current conditions it is not economically practical to install additional seep tents; moreover, the health benefits from ozone reduction are unlikely to justify tenting the marine hydrocarbon seeps in the Santa Barbara Channel. If installing new seep tents is considered in the future, we urge the inclusion of the above recommendations.

Appendix A: Future Gas Pricing

For the purposes of this study, natural gas prices are forecasted for a 20- year time horizon starting in the year 2003. The following discussion presents the theory and computations for 3 methods of price forecasting.

ARIMA

Time series analysis is one method to forecasting natural gas prices in the future. Time series analysis via the *autoregressive integrated moving average method* (ARIMA) method relies upon the past behavior of a time series data in order to model, or forecast the behavior of the time series data in the future [Math Soft, 1999]. The first step in the analysis is to make the time series stationary, because natural gas prices usually trend (the mean price changes over time).   The ARIMA method makes the price time series (P) stationary by taking the differences between each time point, thus creating a new data series, P*. P* is now the input data for the rest of the ARIMA analysis. The general equation modeling P* is

$$P_t^* = \phi_1 P_{t-1}^* + \phi_2 P_{t-2}^* + ... + \phi_p P_{t-p}^* + \varepsilon_t + \theta_1 \varepsilon_{t-1} + \theta_2 \varepsilon_{t-2} + ... + \theta_q \varepsilon_{t-q}$$

where ϕ and θ are unknown parameters and the ε are independent and identically distributed normal errors with zero mean, over time t. Note that this model does not express any descriptive variables as with traditional econometric models, but rather the model expresses P* in terms of its own past values and along with current and past errors. p is the number of lagged values in P*, representing the order of the autoregressive of the model. q is the number of lags in the error term. The parameters ϕ and θ can be estimated via least squares approximation method.

For the purposes of the ARIMA model, the California City Gate natural gas prices were treated two ways. First, the California City Gate natural gas prices for the time period of January 1989 to December 1998 were used. Data from the years 1999 and 2000 was excluded because the addition of large price increases due to the California electricity crisis introduces substantial fluctuations in the ARIMA calculations. Second, the California City Gate natural gas prices for the time period of January 1989 to July 2001 were used; all natural gas prices, including the spike in 2000, were included in the ARIMA modeling to simulate a high forecast.

The order of integration (or the number of times the data was differenced to make the data set stationary) was determined by comparing lag plots of the first and second difference of the data (figures 2a and b). The first order of integration was used because the autocorrelation function shows the correlation of the data to its lag difference were normal after the second period.
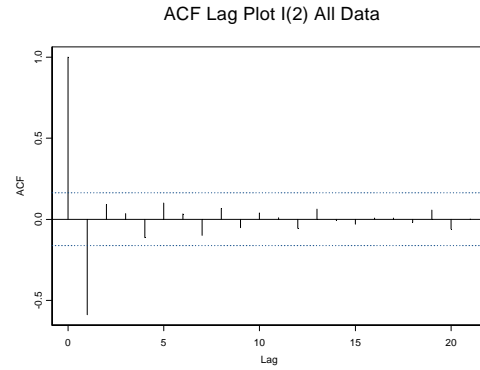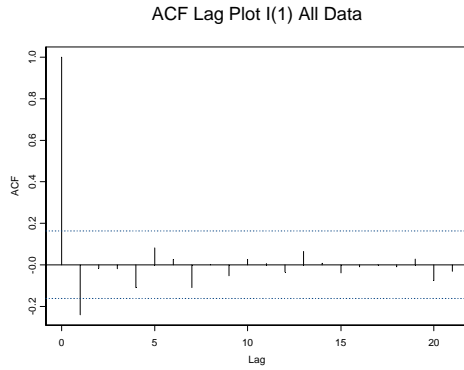
Figure 2a and b: Autocorrelation function plots of the first and second difference of all data (Jan 1998-July 2001)

Biannual periods were used because natural gas prices change depending upon the season. Generally, winter and fall have higher prices than spring and summer because natural gas is mostly used to heat homes.

In order to find out which ARIMA models best fit the natural gas prices, 49 models were tested and their Akaike Information Criterion (AIC) numbers were compared, using SPLUS 2000 Time Series Analysis software (Figures 3a and b). The AIC represents how well the ARIMA model parameters of p and q fit the data. The lower the AIC number, the better the ARIMA model fits the data.

Autoregressive (p)

Moving Average (q)	0	1	2	3	4	5	6
0	X	97	81	83	82	80	80
1	85	86	83	85	82	81	82
2	87	85	82	84	81	82	83
3	**78**	79	81	83	83	83	85
4	80	80	83	85	83	85	86

Table 1a.

Autoregressive (p)

Moving Average (q)	0	1	2	3	4	5	6
0	X	398	396	387	385	383	379
1	401	399	397	389	387	385	380
2	403	401	396	388	386	384	**379**
3	389	395	393	389	388	386	381
4	399	397	395	391	389	387	383

Table 1b.

Table 1a. AIC numbers for ARIMA models of different natural gas prices from January 1989 to December 1989. Table 1b. AIC numbers for natural gas prices from January 1989 to July 2001.

The model with a moving average of 3 and an autoregressive number of 0 best fit the data from January 1989 to December 1998. This ARIMA model was then used to forecast prices 25 years into the future, as shown in Figure 6. Henceforth, this model will be called the Conservative ARIMA forecast.
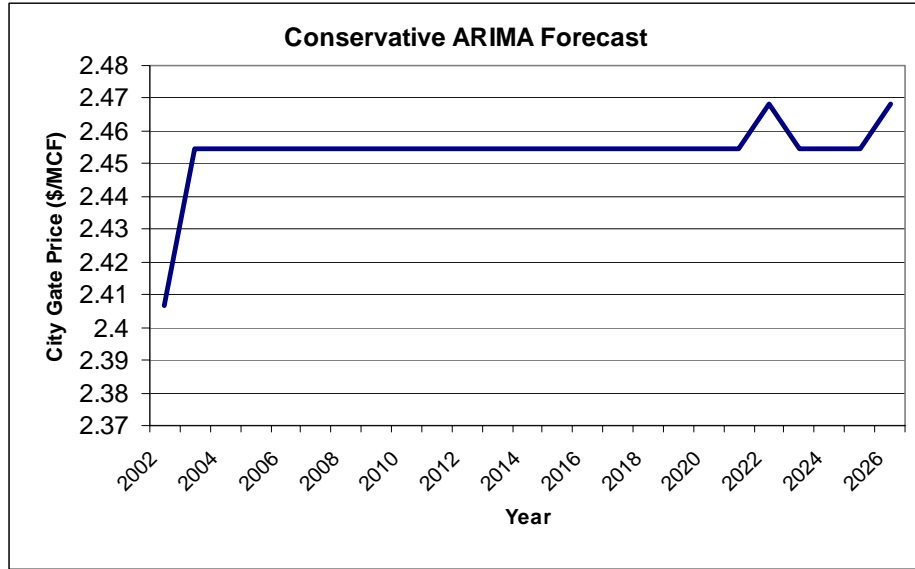
Figure 6: Conservative Natural Gas Price Forecast (ARIMA 0,1,3)

The model with a moving average of 2 and an autoregressive number best fit all the data available from January 1989- July 2001. This ARIMA model was then used to forecast prices 25 years into the future—this forecast is illustrated in Figure 7. Henceforth, this model shall be called the High ARIMA forecast.
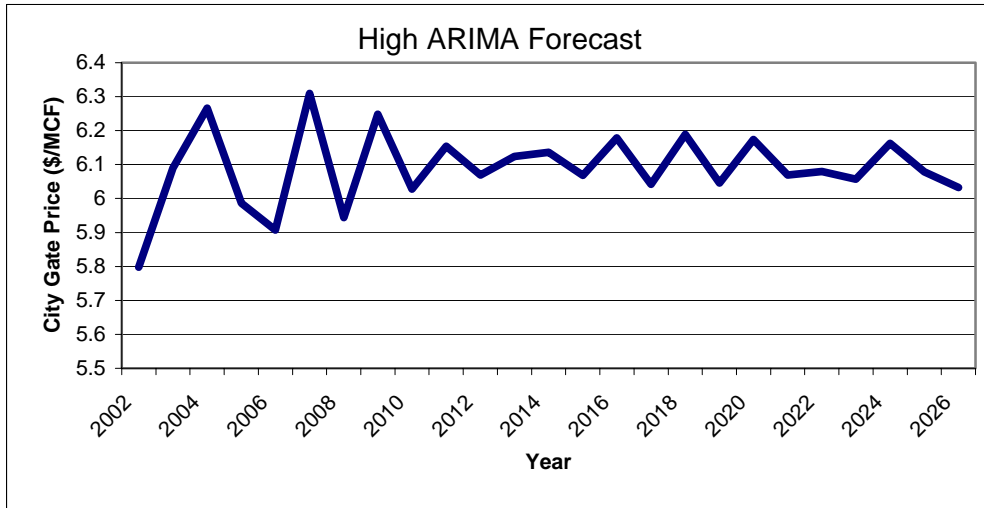

Figure 7: High Natural Gas Price Forecast (ARIMA 6,1,2)

Hotelling Forecast

The Hotelling Principle states that, under certainty about future gas prices and perfect competition among gas producers, the net price (price minus extraction cost) of an exhaustible resource should rise at the rate of return over time as long as it pays to extract some of the resource and leave some un-extracted [Nicholas, 1998]. This condition arises from the requirement that each producer be indifferent between current and future production. The following equation forecasts the future price:

$P_t = P_0(1+r)^t$ where P_t is the predicted price, P_0 is the initial price, and $(1+r)^t$

computes the rate of return over time. Note that this forecast does not incorporate historical prices; it uses the most recent price. For our purposes, a rate of return of 5% and an initial price of $3.00 per MCF are used. The Hotelling forecast shows that by the twentieth year, the price of 1 thousand cubic feet of natural gas is eight dollars (Figure 8).
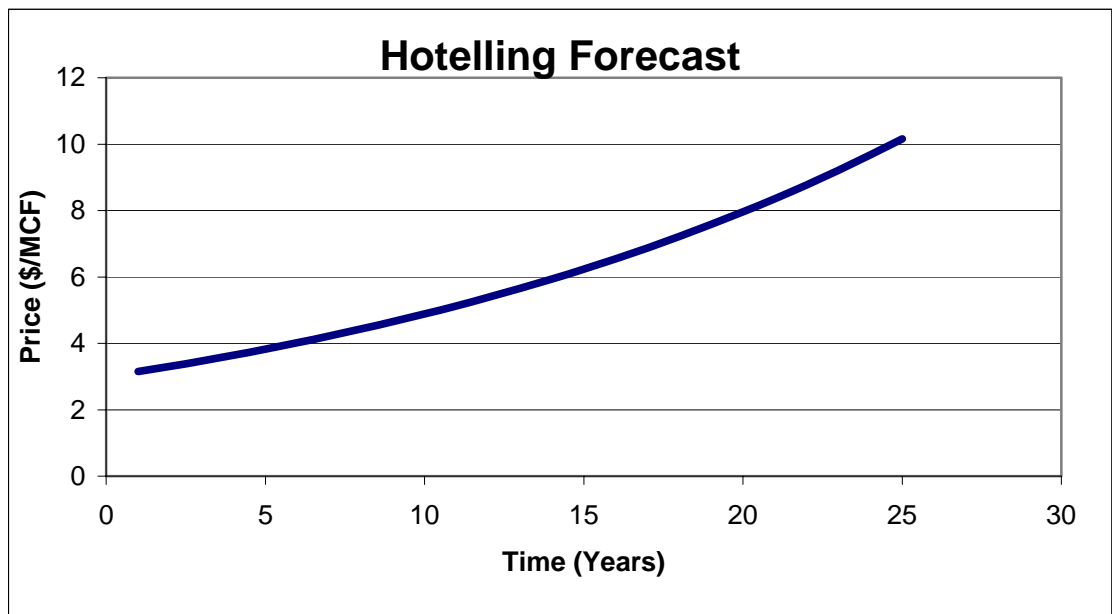
Figure 8: Hotelling forecast r=0.05 P_0= $3.00

Structural Forecasting

Structural models for natural gas pricing take into account known supplies of natural gas, weather predictions (as an indicator of demand) and current market conditions. These factors are modeled to forecast natural gas prices to three years in the future. Due to the nature of the structural model, these forecasts are not considered reliable beyond five years. According to Mike Edwards, a forecast in the range of $2.50-

3.50/MCF is reasonable. We used the average of $3.00/MCF to as a conservative structural estimate of natural gas prices in the future.

Table 2. Summary of natural gas prices predicted using the four forecast models.

Pricing Model	Forecasted Annual Average Price ($/MCF)
Conservative ARIMA	$2.45
High ARIMA	$6.09
Structural	$3.00
Hotelling	$6.01

Appendix B: Derivation of Health Benefit from Reduced Ozone

Methods

As stated previously, the method employed to estimate the health benefits was to use the dose-response functions given in the EPA's compilation of studies, insert the Santa Barbara-specific information that was available, and use their coefficients for the remaining variables. The majority of the dose-response functions follow a typical log-linear form:

(1) Δ health = - [y_0 * $e^{- \beta * \Delta O3}$ – 1] * population

Where the change in health is a function of the rate of illness per person (y_0), a coefficient relating the ozone level to the change in health (β), the change in the ozone concentration in ppb (ΔO_3), and the population of the study area.

For the third coefficient, population, 1999 Santa Barbara County census data was used. However, since it is unlikely that the entire population of the county is affected by seeps-caused air pollution only the cities of Santa Barbara and Goleta will be considered. The total population of the county (391,071) was not used, but instead the city of Santa Barbara plus two-thirds of the remaining population that does not reside in the county's six other cities for an area total of 195,863 [USCensusBureau, 2001 #47]. This two-thirds estimate was used as a proxy for the township of Goleta, which is not recorded in census data.

For each of the eleven categories of health effects, the variables listed above were inserted into the dose-response functions and a resulting decrease in incidence per year was determined. Using literature values from the same EPA report, the annual dollar value of this change in health was then calculated. As the EPA study values were in 1990 dollars, a conversion was made using consumer price index inflation data (CPI). A review of each category is provided below; an interpretation of the results and their applicability to Santa Barbara is addressed in the discussion of section 5.4.

Results

Unless stated below, the log-linear function was used. Results are listed in order of increasing total value. Because the coefficients used were determined from city-specific data, the city of study is also listed.

Hospital Admissions – Asthma

There was a 0.00053 reduction in incidence of asthma admissions per year. The cost of moderate or worse asthma was $32.00 per incidence, resulting in a reduction value of $0.02 per year (Burnett et al. 1999, Toronto, Cananda).

Hospital Admissions – Respiratory Infection

The reduction in incidence of hospital admissions for respiratory infection per year was 0.00138; at $18.00 per incidence of acute respiratory symptoms the reduction value was $0.03 (Burnett et al. 1999, Toronto, Canada).

Hospital Admissions – All Respiratory

The cost of any respiratory symptom was determined to also be $18.00 per incidence. Using coefficients from Burnett et al. (1997, Toronto, Canada) a reduction of 0.0057 in hospital admissions for respiratory illnesses was found, with a reduction value of $0.11. Also from Toronto data, Thurston et al. (1994) data gave a 0.00075 reduction at a value of $0.01. A separate calculation was made for hospital admissions for respiratory illness in the elderly. The function is the typical model but uses only the population 65 years of age and older. Coefficients from Schwartz (1995) resulted in a 0.0017 reduction valued at $0.03 from New Haven, Connecticut data, and a reduction of 0.0048 valued at $0.09 from Tacoma, Washington data.

Emergency Room Visits – Asthma

This illness category uses the following function:

(2) $(\beta/\text{BasePop})* \Delta O_3 * \text{population}$

Where BasePop is the baseline population in geographic area. The studies listed were for New Jersey and used the baseline population of northern New Jersey. The baseline population used for the calculations in this paper was the entire population of Santa Barbara County. The cost of emergency room visits for asthma was determined to be $194.00 per incidence. Results from three studies' data were calculated. That of Cody et al. (1992, Northern NJ) returned a 0.0023 reduction in emergency room visits for asthma, with a reduction value of $0.45. Data from Weisel et al. (1995, Northern NJ) gave a 0.0050 reduction in emergency room visits for asthma, with a reduction value of $0.99. Steib et al.'s (1996, New Brunswick, Canada) coefficients returned a 0.0004 reduction, with a reduction value of $0.08.

Self-Reported Asthma Attacks

The function for incidence of self-reported asthma attacks takes a more complex form:

(3a) $$\Delta asthmaattacks = -[\frac{y_0}{(1-y_0)* e^{\Delta O_3 * \beta} + y_0} - y_0]* pop$$

The variables used are the same as the log-linear function. The reduction in asthma attacks was 0.12, and with a central estimate of $32.00 per attack, the reduction value was $3.89 (Whittemore and Kom 1980, Los Angeles, California). It is important to note that because the study was for the Los Angeles area, where the ozone air pollution is infamously poor, the results are likely an overstatement for Santa Barbara.

Minor Restricted Activities Days

These results returned a 1.316 reduction in MRADs per year. At $5.30 per incidence of minor symptoms the reduction value is $6.98 (Ostro and Rothschild 1989, U.S.). Again, the study used data from the entire country and thus is not site-specific to Santa Barbara. Yet, the value is only of the minor symptoms and does not include costs of lost work time or productivity. The magnitude of these two inaccuracies' effect on the results is unclear.

Acute Respiratory Symptoms

The incidence value for any of the symptoms is $18.00. This study of the Glendora-Covina-Azusa areas of California used a simple linear function to relate the ozone effect on health to the change in ozone over a specific population:

(4) Δ acute respiratory symptoms $= \beta * \Delta O_3 * pop$

The reduction in incidence of respiratory symptoms per year was 3.83, resulting in a reduction value of $72.91 (Krupnick et al. 1990).

Hospital Admissions – Chronic Obstructive Pulmonary Disease (COPD)

COPD carries a lifetime value of $260,000.00. The value is the mean of a Monte Carlo distribution of willingness to pay responses to avoid pollution-related chronic bronchitis (from Krupnick and Cropper 1992). Moolgavkar et al. (1997) used data from Minneapolis, Minnesota, and their coefficients resulted in a 0.00058 reduction in incidence of chronic pulmonary disease. This is valued at $152.24. Secondly, Schwartz's (1994) coefficients from Detroit, Michigan gave a 0.00095 reduction, with a value of $248.01. Because of the nature of these diseases the studies controlled for smoking. Two studies evaluated this function, both in northern Midwest industrial cities, so the very low reduction in incidence values may in fact be even lower for Santa Barbara.

Adult Onset Asthma

This dose-response function is the same as self-reported asthma attacks, but with differing coefficients:

(3b)

$$\Delta asthma = -[\frac{y_0}{(1-y_0)*e^{\Delta O_3 * \beta} + y_0} - y_0]* pop$$

A value was used of $25,000.00 for chronic asthma, and again note the much higher cost of chronic disease. The reduction in incidence of adult onset asthma was 1.01, giving a reduction value of $25,424.34 (McDonnell et al. 1999, California). Smoking could also be a significant cause, so the study controlled for respondents ever having smoked; it, like all studies cited in this paper, also controlled for other pollutants. The study found that long-term exposure to ambient ozone was only associated with development of asthma in adult males, thus the population used in the calculation was duly adjusted.

Mortality

The coefficients from four studies were used to determine different risk reduction levels and valuation amounts. The first by Ito and Thurston (1996, Chicago, Illinois) gave a 0.12 reduction in incidence of mortality, in other words 12 100ths less of a chance of dying from an ozone-related illness. The second, from Los Angeles, California, showed no reduction in the incidence of mortality (Kinney et al. 1995). A reduction of 0.11 was found from the third (Moolgavkar et al. 1995, Philadelphia, Pennsylvania). Fourthly, a reduction of 0.18 resulted from the study data of Samet et al. (1997, Philadelphia). The values associated with each reduction are shown in table X of Chapter 5 for both the $1.5 M and $9 M values of a statistical life.

Final Note

These values were calculated under the assumption of an ROG-limited ozone production regime in Santa Barbara County. To achieve the more likely situation of ROG and NOx co-limitation, only 50 percent of each of these values was used in the integrated computer mode.

Appendix C: Spatial Flux Tent Capture Calculations and Temporal Decline

Spatial Flux Capture Calculations

The data was analyzed using MATLAB 6.0.0.88 Release 12 software in the following methodology. The dataset was checked for non-numerical values, and a new dataset was created consisting of only the numerical data points from the initial data set. A correction factor 0.003 was subtracted from each of the data points, according to Washburn et al's discussion of the sampling bias. The mean and standard deviation were determined. Data points outside of 10 standard deviations were excluded from the dataset to eliminate outliers. This correction eliminated 168 data points out of the 96,000 in the dataset, equivalent to less than two tenths of one percent. A vector was then created of latitude and longitude values that identified a 30 by 30 meter, the area of a seep tent, grid over the sample area. This grid started just outside of the sample area at 34.37˚ latitude and ended at 34.4102˚. The same grid was run for longitude from 119.83˚ to 119.9002˚. The program also created a directory of how many data points fall into each latitude and longitude grid bin, and to which bin each data point belongs. A matrix was then created of latitude and longitude bins across the study area, resulting in 30 by 30 meter "grid cells." Each cell was given a starting value of zero; then, data points were systematically allocated to and summed in the grid cell in which they were located. An average for each cell was determined by dividing the cell total by the number of data points in that cell. The top 100 cells, or tent locations, were then sorted in descending order, and a plot of flux capture by the number of tents was created from that list.

The goal was to determine the flux capture per seep tent, creating a declining function of capture per tent. The first tent would, of course, be placed over the area of highest flux within the seep field; the second would be slightly lower, and so on. This procedure could be followed until an additional tent would not capture enough seep gas to be profitable. A regression was run to determine the coefficients for the function:

$$F = \beta \, x^{-\alpha}$$

F is the total flux captured by x number of tents. β is the flux capture of the first tent. α was determined to be -0.8161. The regression had a multiple R^2 value of greater than 0.99, indicating that the model fit the data very well. The figure below shows the plotted data and the fitted regression.
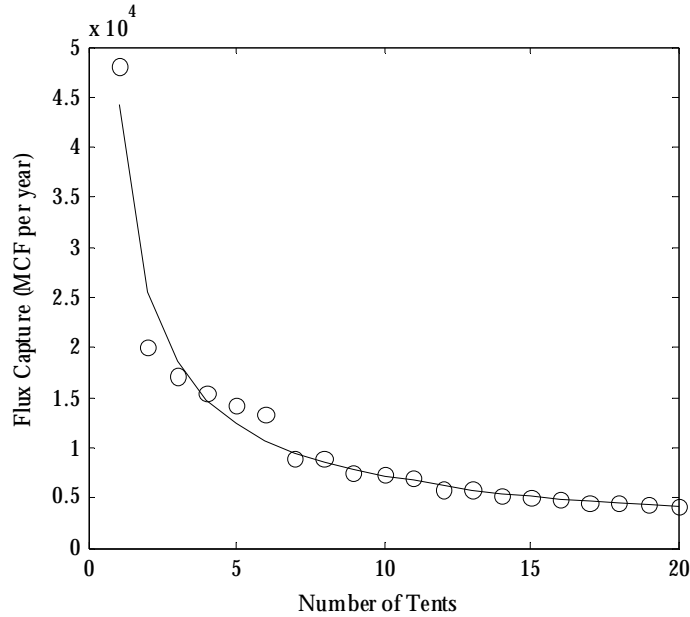
Figure 1. Plot of actual flux capture per tent (circles) and function fitted to this data.

The function was then integrated to determine the total gas capture of x number of tents at any starting point of gas capture:

$$F = \beta \, (x^{1-\alpha} - 0) \, / \, (1-\alpha).$$

The flux estimates generated does not match the empirical capture flux of the original ARCO tents, it is much lower. This could be due to many factors, but most likely is a result of the data set used.

In order to test different flux capture scenarios, we change the intercept (parameter β) in the integrated function equal to the starting capture, C, multiplied by $(1-\alpha)$. The resulting equation is:

$$F = C \, (1-\alpha) \, (x^{1-\alpha} - 0) \, / \, (1-\alpha) \text{ or } F = C*(1 - 0.8161)*(x^{1-0.8161})/(1-0.8161).$$

With a starting flux of 220,000 MCF per tent per year (ARCO Tents 1982 capture rate), and project with 5 tents, the equation produces a total flux of 295,776 MCF per year, as shown in the computation below .

$$F = 220,000*(0.1839)*(5^{0.1839})/0.1839 = 295,776$$

Spatial and Temporal Seepage Decline Calculation

As discussed in Chapter 2, there is natural spatial and temporal variation of hydrocarbon seepage over time. Hydrocarbon seep rates have been declining near Coal Oil Point [Boles and Clarke, 2001]. In order to mimic this variation, a linear regression (using the statistical analysis software S-Plus 2000) was performed on a decay model with the variables of time (t) and Flux:

$$Flux = \alpha e^{-\beta t}$$

where the coefficient α is the intercept and β equals the percent change in the flux. The results of the linear regression were: $Flux = 49300.431 e^{-0.074t}$, with an R^2 of 0.63. Thus, 7.4% was chosen as the temporal decline in seepage.

Appendix D: Cost Effectiveness Calculations

The following methods are used to calculate the marginal cost of ozone abatement, and ROG and methane emissions reduction.

Marginal Cost of Ozone Abatement

A useful way to compare our cost-benefit analysis results to other pollution prevention methods is through the marginal cost of ozone abatement. We numerically deduce these marginal costs from the data produced by the model. In order to determine the marginal cost of ozone abatement for a potential seep capture tent project three steps are undertaken. First the total marginal costs for 1-20 tents are defined. Then, the marginal ozone reduction over twenty years is described. Finally, the two are put together to calculate the net marginal cost of ozone abatement.

Total costs of the project are calculated as the design, capital, installation and maintenance costs for the twenty-year life of the project. The marginal cost is equal to the total cost of putting in an additional tent in the Santa Barbara Channel. Total revenues from gas sales using conservative pricing from the most likely scenario are calculated over the twenty-year life of the project as well. Marginal revenue is the addition benefits accrued from gas sales by installing an additional tent.

Figure 1 shows the marginal costs (dark blue) and marginal revenues from gas sales (pink) for tents 1-20. The net marginal cost of this project is evaluated by using the total project cost less the revenue generated by gas sales. Note that the net marginal cost (shown in yellow) is only slightly lower than the marginal cost of the project after 3 tents. This is due to the fact that there is a rapid decline in seep gas capture. Also note that there is a plateau in both cost curves. This is due to the pricing function used in determining the capital and installment costs of the tents that assumes a constant marginal cost for tents 10-20 (see Section 5.5).
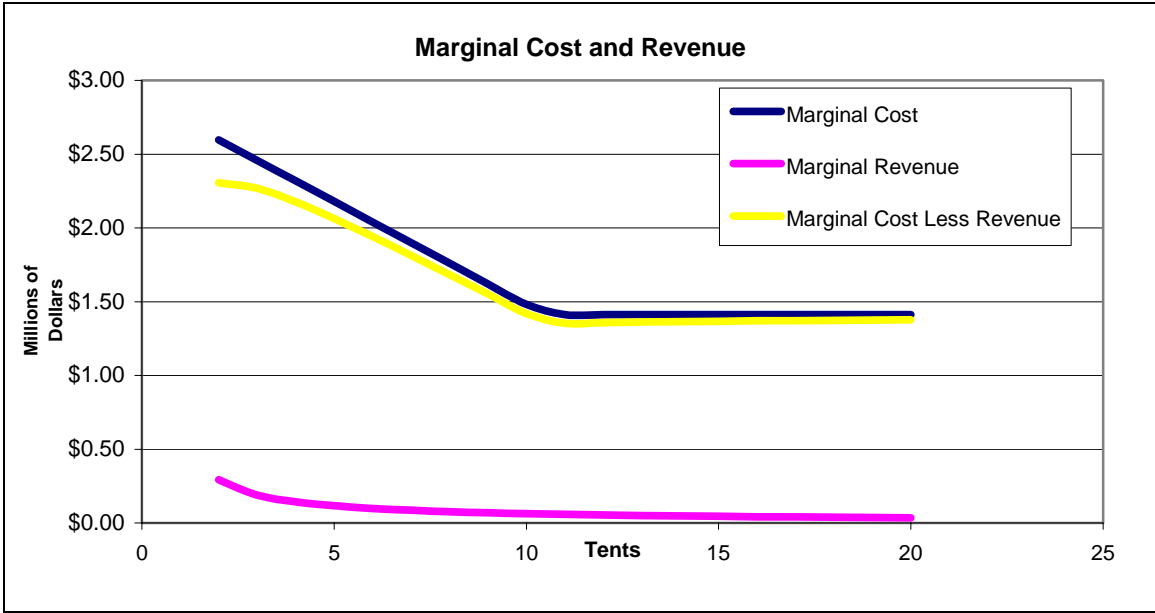
Figure 1: Marginal cost and revenue for the most likely scenario.

A twenty-year average is used to for the determination of ozone reduction per tent. As shown in Figure 2, the ozone reduction (pink line) increases slowly from approximately 0.45% to nearly 0.8%. The marginal ozone reduction over twenty years is the additional ozone reduced by installing one more tent. Note that marginal ozone reduction (dark blue line) decreases rapidly and asymptotes near the eighth tent (Figure 2).
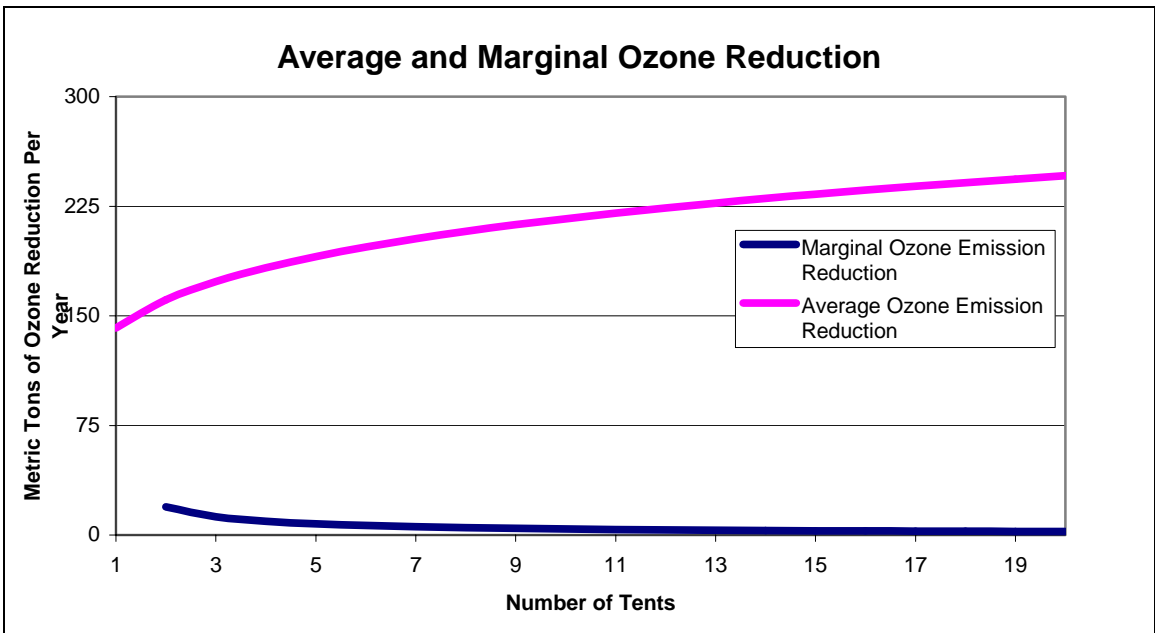

Figure 2. Average and marginal ozone reduction averaged over twenty years for each tent.

Figure 3 shows the marginal cost of ozone abatement. The line is deduced by plotting the total marginal cost of the project against the marginal reduction of ozone. Note that the marginal cost of ozone abatement decreases until the tenth tent. This occurs for two reasons. First, as previously stated, the cost function for the capital and installment cost of the tents introduces a plateau at the tenth tent. Second, the cost of installing more tents declines more rapidly than the amount of ozone reduced for the first though tenth tent. After the tenth tent is installed, the line flattens out and begins to trend slightly higher. At the same time, there is very little ozone being reduced despite adding the additional tents. Therefore, the line flattens at 10 tents.
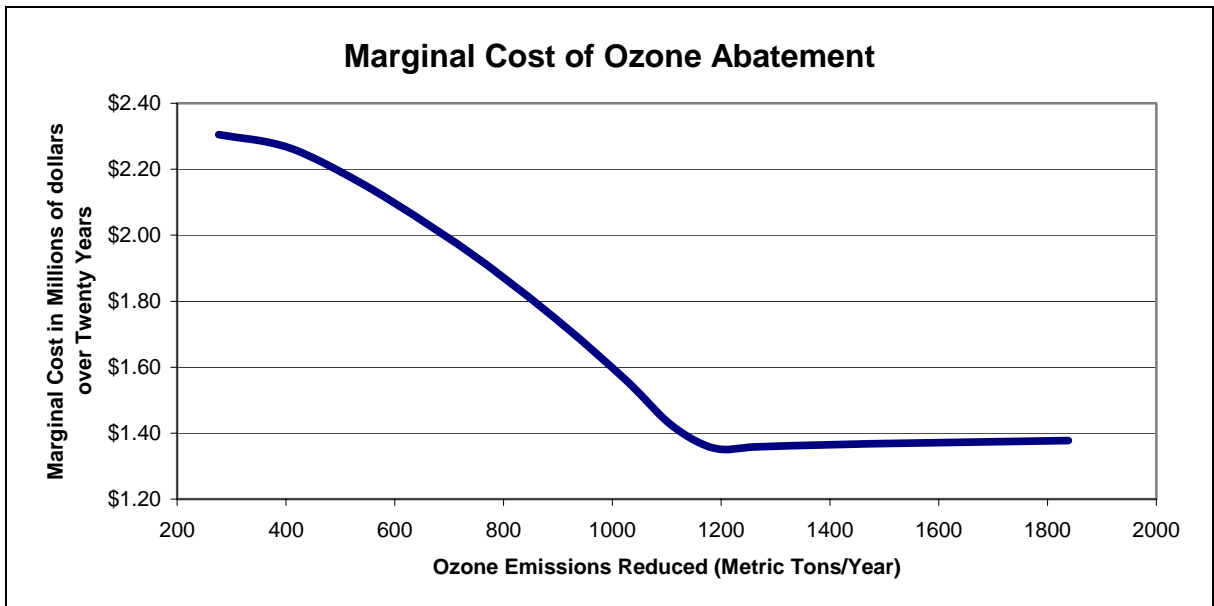
Marginal Cost of Ozone Abatement

Figure 3. Marginal cost of ozone abatement. The dark blue line represents the total marginal cost of installing an additional tent versus the amount of ozone being reduced by the total number of tents.

Table 1 describes the marginal cost of ozone abatement for various numbers of tents. The marginal cost of ozone abatement is about $16,000 per ton of ozone reduction for the first tent over 20 years. The marginal cost decreases as the number of tents increases. This is unusual for a marginal cost function, and is due to the cost function used in calculating the costs of the tents.

Table 1. Marginal cost of ozone abatement in dollars per ton over twenty years.

Tent	Marginal cost of ozone abatement ($/ton)
1	$16,000
5	$11,300
10	$6,700
20	$5,700

Value of Methane Emission Reduction

As discussed in Chapter 3, the Global Warming Potential for methane in the atmosphere is about 25 times greater than carbon dioxide over a life of 100 years, and 62 times greater then carbon dioxide over a life of 20 years. For this comparison, we will assume that the trading cost for methane equals carbon dioxide. Given that methane has a molecular weight of 16 and that carbon dioxide has a molecular weight of 44, methane has an equivalent weight of 0.36. Table 2 generates the trading costs associated with emissions equal to 1 metric ton of carbon dioxide.

With the installation of one seep tent, our calculations indicate that 3604 metric tons of methane will be captured. This amount of methane is equivalent to approximately 123,900 to 614,500 metric tons of carbon dioxide in terms of global warming potential.

Table 2. Varying values of emissions trading for carbon dioxide and methane.

Trading Cost Associated With 1,000 Metric Tons of CO_2					
Greenhouse gas	Equivalent Weight*	Price	GWP	Cost per metric ton**	Total Trading Cost**
Carbon dioxide	1	$2.50	1	$2.50	$2,500.00
Carbon dioxide	1	$6.00	1	$6.00	$6,000.00
Methane - 20 year life	0.36	$2.50	25	$0.04	$36.36
Methane - 20 year life	0.36	$3.80	25	$0.06	$55.27
Methane - 20 year life	0.36	$4.33	25	$0.06	$62.98
Methane - 20 year life	0.36	$6.00	25	$0.09	$87.27
Methane - 100 year life	0.36	$2.50	62	$0.01	$14.66
Methane - 100 year life	0.36	$3.80	62	$0.02	$22.29
Methane - 100 year life	0.36	$4.33	62	$0.03	$25.40
Methane - 100 year life	0.36	$6.00	62	$0.04	$35.19
*Equivalent Weight = molecular weight CO2 / molecular weight CH4 ** Trading Cost = equivalent weight * price / GWP					

Appendix E: Greenhouse Gas Emission Trading

The following table represents the synthesis of various types of transactions involving carbon dioxide and methane.

Emission Trading: Examples of Transactions			
Participants	Emission Type	Transaction	Cost ($ per unit)
Arizona Public Service (APS) and Niagara Mohawk Power Company (NMPC)	CO2 emission reductions and SO2 emission allowances	In December 1996, Niagara Mohawk transferred 2.5 million tons of CO2 reductions achieved through its emissions reduction activities to APS. In return, APS transferred SO2 allowances to NMPC. Instead of releasing the SO2 into the atmosphere, NMPC donated the 20,000 SO2 allowances to three non-profit environmental organizations for permanent removal from the emissions-trading market. The tax benefit associated with the donation, expected to be about $650,000, will be reinvested in projects to further reduce CO2, including a CO2 reduction project in Mexico.	The value of the CO2 reductions was estimated at $2.70/metric ton of carbon, based on the market value of SO2 allowances.
Government of New Zealand	CO2	New Zealand officials have proposed a pilot trading program which could be running next year until a comprehensive domestic emissions trading system is implemented (as early as 2005). The basis for setting the rate will be what the international market price of carbon emission reductions will be in 2010 valued in present dollars.	An expected range of about $2.50-$5.00 (US) per metric ton of CO2 in 2000.
British Petroleum (BP)	CO2	In 1997, BP announced that it is setting up a pilot program of internal emissions trading across selected diverse business units worldwide. The plan will help meet the 10% reduction by 2010 that CEO John Brown set last year. The pilot started in September 1998. So far, twelve business units, accounting for 25% of BP's CO2 emissions, have volunteered to participate. BP is looking to expand the pilot to a corporate-wide trading program by June 2000. Five transactions have already been yielded, exchanging 49,000 metric tons of CO2 emissions. The program covers refineries, pipelines, and chemical plants in the US, UK, Spain and Australia. If each business unit falls short of covering its emissions at the end of each year, it must go to the BP market as a distressed buyer, otherwise it faces a fine at a multiple of the highest permit price during the year. No borrowing is allowed either.	The first trade for allowances was at the price of US $17 per metric ton of CO2. The last trade was at $22.
Consorcio Noruego and the Government of Norway	CO2	In July 1996, this consortium of three private Norwegian companies and the Government of Norway agreed to purchase 200,000 creditable, tradeable offsets (CTOs) from the Costa Rican government for $2 million. The purchase was made in conjunction with the expansion and reconstruction of a hydro electric plant in Costa Rica with work done by the Norwegian group. The money will be used for reforestation and forest conservation as part of Costa Rica's nationwide Joint Implementation initiative, the Private Forestry Project.	$10 per metric ton of carbon
Government of Denmark	CO2	Denmark has set for itself ambitious GHG emissions reduction targets and has set up a CO2 cap and trade scheme (only for the electricity sector) for the years 2000-2003. This system will help reach Denmark's -5% GHG emissions target in year 2000 compared to 1990, its national target of -20% CO2 in 2005 compared to 1988, and its Kyoto and EU bubble of -21% GHG's in 2008-2012 compared to 1990.	If companies do not comply with their respective caps they will be subject to a penalty of DKK40 (US$6)/ ton CO2

Emission Trading: Examples of Transactions - Continued			
Participants	Emission Type	Transaction	Cost ($ per unit)
Greenhouse Gas Emissions Reduction Trading (GERT) Pilot project in Canada	CO2	Various offers to sell projects in the GERT pilot • Downie Timber Ltd.; 20,130 tonnes at CAN$10.00 (Approx. US$6.67) per tonne • Pacifica Papers's Powell River Biomass Boiler Project; 117,000 tonnes at CAN$4.50 (Approx. US$3.00) per tonne • British Columbia Power Exchange Corporation (Powerex); Estimated at 10,150 tonnes CO_2 equivalent per year at CAN$2.00 to CAN$5.00 (Approx. US$1.33 to US$3.33) per tonne, price is negotiable • Mikro-Tek (a division of M. Kean Resources Inc.) reforestation project; 18,750 tonnes CO_2-equivalent per year at CAN$5.00 (Approx. US$3.33) per tonne, price is negotiable	Projected Present Value ranged from CAN$2.00 to CAN$10.00 (US$1.33 to US$6.67) per tonne of CO_2-equivalent
Greenhouse Gas Emissions Reduction Trading (GERT) Pilot project in Canada	Methane (CH4)	Various offers to sell projects in the GERT pilot • Compost Management - Avoiding Methane Emissions: Diverting Waste from Landfill to Composting Facilities in Southern Ontario; 31,422 tonnes at CAN$6.50 (Approx. US$3.80) per tonne • JNE Consulting Ltd. Xiangfan, China Landfill Gas Power Generation gas recovery project; 4,488,853 tonnes at CAN$5.70 (Approx. US$4.33) per CO_2-equivalent (note: reduced from CAN$14 on June 15, 1999)	Projected Present Values estimated at CAN$5.70 to $6.50 (US$3.80 to US$4.33) per tonne of CO_2-equivalent
Information in this table was gathered from Greenhouse Gas Emission Reduction Trading Pilot (GERT) (www.pert.org), Pilot Emission Reduction Trading Project (PERT) (www.gert.org), and United Nations Conference of Trade and Development (UNCTAD) (www.unctad.org/en/subsites/etrade/initiatives.htm) press releases and compiled in 1999 and 2000 (Olson 2002).			

Source: (Leonardo Academy, 2002). Note: Per personal communication (Olson, 2002).

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