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# Cap and Trade and Structural Transition in the California Economy

David Roland-Holst

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**DEPARTMENT OFAGRICULTURAL AND RESOURCE ECONOMICS**
207 GIANNINI HALL
UNIVERSITY OF CALIFORNIA
BERKELEY, CA 94720
PHONE: (1) 510-643-6362
FAX: (1) 510-642-1099
WEBSITE: are.berkeley.edu

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# Research Papers on Energy, Resources, and Economic Sustainability

This report is part of a series of research studies into alternative energy and resource pathways for the global economy. In addition to disseminating original research findings, these studies are intended to contribute to policy dialogue and public awareness about environment-economy linkages and sustainable growth. All opinions expressed here are those of the authors and should not be attributed to their affiliated institutions.

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# Executive Summary

California has the innovation capacity to achieve its Climate Action objectives without compromising economic growth, as a variety of official, officially sponsored, and independent studies have demonstrated. While the state's aggregate income and employment can actually be stimulated by the right package of policies, including a cap and trade system to reduce CO2 emissions, the structural adjustments that ensue will be complex and far reaching. While no substantive mitigation policy can be without some direct and indirect costs, the benefits from greater energy efficiency and improved environmental conditions can significantly outweigh these. Thus responsible climate action assessment requires consideration of both the magnitudes and composition of adjustment costs and benefits. The primary objective of this report is to strengthen the basis of evidence in this area. To effectively limit costs and facilitate the innovation needed to sustain and propagate the benefits of a more carbon-efficient future, policy makers need better visibility regarding adjustment processes.

This study reviews an extensive body of evidence at the industry level, examining publically available information on the technology and cost structures of so-called first and second-tier emitters in California. These sectors are most likely to be included in a cap and trade system because they make large aggregate or relative contributions to CO2 emissions and can therefore make important contributions to reducing climate change risk. Our general finding is that all these sectors can make the needed contributions, particularly under a well-designed cap and trade system that uses a market mechanism to more efficiently allocate the burden of adjustment.

More detailed characteristics of the adjustment process remain uncertain, but some impacts could be substantial at the industry and particularly the plant level. The actual magnitudes will depend critically on the incentive properties of the policy design. For example, the degree to which firms pass on adjustment costs to consumers will depend upon competitive conditions in each industry and the extent to which policies promote investment in efficiency. If the state is to maintain its leadership as a dynamic and innovation oriented economy, it is essential that Climate Action policy

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include explicit incentives for firms to follow competitive innovation discipline, investing in discovery and adoption of new technologies that offer win-win solutions to the challenge posed by climate change for their industries and for consumers. In this way, California can sustain its enormous economic potential and establish global leadership in the world's most promising new technology sector, energy efficiency, as it has done so successfully in ICT and biotechnology.

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# Cap and Trade and Structural Transition in the California Economy

David Roland-Holst[1]
UC Berkeley

## 1. INTRODUCTION

Climate change will have serious impacts on the state of California and is now widely recognized as an important risk to the economic activities and living standards of present and future generations. In response to this, the state has extended its long commitment to sustainable economic growth by implementing a series of initiatives for energy efficiency and GHG emissions reduction. In the latter category, Assembly Bill 32 represents landmark legislation to address climate change risks and move the California economy to a path of greater energy efficiency, productivity, and reduced environmental risk.

The central provision of AB32 is a set of targets for greenhouse gas (GHG) mitigation, to be achieved at least in part by a market oriented mechanism like a cap-and-trade scheme. While cap and trade is widely acknowledged for its potential to enlist market

[1] Department of Agricultural and Resource Economics. Correspondence: dwrh@are.berkeley.edu.

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forces and private agency for efficiency improvement, the empirical evidence on detailed economic impacts of these policies remains weak. In this report, we evaluate the implications of policies like the proposed CO2 cap and trade system using a dynamic simulation model of the state economy.

The research reported here extended macroeconomic analysis developed to inform the legislative dialogue on AB32 during the summer of 2006 (Roland-Holst:2006b). While the macro results indicated that California's growth and environmental objectives can be reconciled, they did not provide much detail on the structural adjustments that would attend this process. Perhaps for this reason, some observers (e.g. Stavins et al: 2007) mistakenly interpreted this work as promoting no cost solutions. In fact, any substantial climate action in California and any other modern economy will entail costs, but these can be substantially or completely outweighed at the aggregate level by offsetting benefits. Because detailed costs and benefits may accrue to different stakeholders, responsible climate action assessment requires consideration of both the magnitudes and composition of positive and negative adjustment effects. The primary objective of this report is to strengthen the basis of evidence in this area, and much more research could be productively undertaken to elucidate effects of complex policy alternative in greater detail. As part of this effort to better understand the economic adjustments that might ensue from cap and trade approaches to GHG regulation, a comprehensive review was conducted of publically available information on technology and cost structures in the state's first and second-tier GHG emitting industries. These information resources are summarized in four sections of this report, corresponding to Electric Power, Cement, Petroleum Refining, and Chemicals. While may insights have been gained in this process, the information in public hands remains too fragmentary to reliably predict detailed incidence patterns in these sectors.

Despite these limitations, this report attempts to improve general understanding of the salient forces at work within prominent individual industries. In doing so, it is possible to reach a variety of important conclusions, if not to identify individual enterprise winners and losers or plant-specific quantitative adjustments. Such detail would of course be of interest to enterprises, both those directly affected and those in competitive or contractual relationships with affected firms, but it is outside the scope of this analysis.

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Several important messages for policy makers and stakeholders emerge from this review and analysis. For example, policies that restrict GHG emissions, while socially desirable, can lead to unintended adverse effects if they are defined too narrowly. When they impose new costs on industries, they also risk transferring those costs to society through the price system. More complete policies will recognize the combined potential of economic competition and investment in efficient technology to mitigate new cost/price pressures that arise in targeted industries.

Industries with high levels of competition will experience efficiency gains more spontaneously, as new entrants and incumbents seeking new market share invest in competitive innovation voluntarily. In other contexts, investment incentives can be provided, perhaps from resources generated by pollution licenses. In either case, explicit recognition and facilitation of the essential role played by innovation can hel secure win-win outcomes for both industry and society.

At a more detailed level, we draw conclusions about the adjustment process in several industries. For example, in the face of significant potential cost increases, the electric power distribution sector is likely to make important compositional adjustments in its generation portfolio over the next decade. Because the working life of these capital goods spans several decades, these decisions will establish new baselines for emission intensity and accelerate the need for future efficiency improvements.

In the cement sector, we infer that conformity to new GHG standards, even under relatively efficient cap and trade regimes, will confer nontrivial costs on this sector, and these will either be passed on to consumer, reinforce innovation incentives, or some combination of the two. Another unresolved issue in this sector concerns the potential of blended cement to offset this sector's carbon liability. The industry's largest individual customer, a public agency, is undecided about whether or not blended cement will meet its needs. This deadlock poses an important obstacle to the industry's strategy for meeting the state's own environmental objectives, and it also denies the cement market and essential precedent of adoption. Finally, there has been considerable discussion about the long term viability of within-state cement operations. It should be noted, however, that in no scenario we consider do Climate Action costs approach the kind of pressures the sector has repeatedly experienced

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from its energy fuel inputs. For this reason, it is difficult to imagine California's cement industry experiencing any relocation adjustments.

Oil refining is an exceptionally challenging industry for analysis because of the diversity of its product mix and pervasive linkages across the economy. Because it is the primary channel for GHG production by all forms of transportation and a significant component of other manufacturing activities, its response to GHG policies will have a very significant indirect component. Indeed, indirect mitigation of refinery emissions from attenuation of fuel demand trends can account for up to half this sector's GHG mitigation. This being said there are still significant opportunities for process innovation to achieve higher efficiency levels in this sector, although restrictions on new capacity development may retard this process.

The chemicals sector is another example of a very diverse sector with strong indirect linkages. As a California manufacturing sector, it is second in GHG emissions only to Petroleum refining. Despite this, the largest component of the industry, pharmaceuticals, bears indirect responsibility for most of its GHG emission through electricity and energy intensive input demands. Opportunities for process innovation are considerable across this sector, but it is clear that no single prescription for technological change or other structural transition will fit all cases in such a diverse environment. More than any industry considered in this study, chemicals demonstrates the value of market oriented policies that enlist private agency to find individual solutions that fulfill public objectives.

In the next section, we discuss the scenarios used to study cap and trade's economic effects in California, with particular reference to the so-called First-tier Emitter sectors. Following this, we discuss each major sector in greater detail, reviewing available data on industry structure and conduct and explaining how each sector was implemented in the model. Section 3 covers the Electricity Production and Distribution sector, followed in Sections 4-6 by Cement, Oil Refining, and Chemicals. The report closes with summary remarks and a discussion of how this framework will be extended to provide more extensive support for climate action policies.

A series of annexes follows the main study. The first of these provides a general description of the Berkeley Energy and Resources (BEAR) model, which is fully

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documented in (Roland-Holst:2005). Also included, in the order of industry presentation in the study, are subsidiary tables and data sources.

# 2. SCENARIOS FOR CLIMATE ACTION

California has well-established leadership in policies related to climate change, including a broad spectrum of energy and emissions initiatives that have set national standards for economic growth through innovation and efficiency. These policies have targeted energy efficiency and air pollution from many different angles, including vehicle, appliance, and building standards, tax credits, and now economywide emissions targets. While the approaches are diverse, most of these policies share the important objective of seeking to influence economic behavior in ways that limit adverse environmental consequences. Thus climate action policies seek to change behavior, which in turn alters economic structure by inducing agents to choose different technologies, goods and services, and other modalities of economic behavior.

## 2.1. Economic Behavior and Structural Transition

To understand these induced adjustments, we focus on a triad of behavioral elements (Figure 2.1): Household consumption/adoption, Firm investment/adoption, Firm price setting. Consider a cap and trade policy that imposes a ceiling on GHG emissions, allowing firms to buy permits if they exceed their initial allowances. If the ceiling is binding, the policy gives rise to a new cost in the economy, having created a market for a negative externality. What this represents is the cost of re-allocating pollution rights that were until now unpriced. In response to the new cost, firms have two options, to increase prices or efficiency levels. In the first case, the firm must have sufficient market power to pass through the cost to prices paid by downstream buyers of their product. The second option requires firms to invest in technology adoption that will reduce emissions, increase profits, or both, to offset the new cost. In general, it is reasonable to expect an industry to adapt with a combination of price

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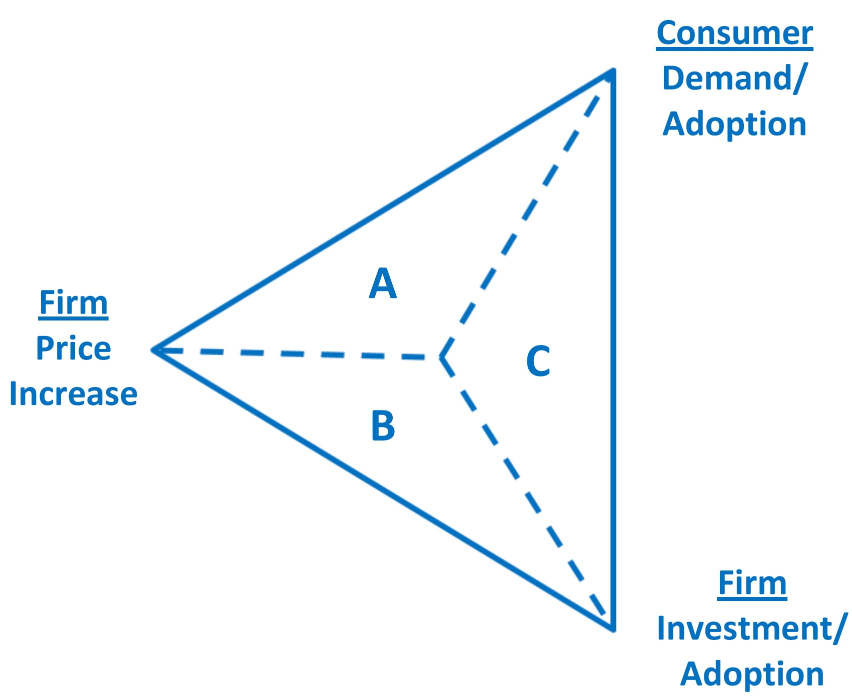
and investment/adoption responses, but this depends on market conditions and technology choices.

The third corner of the triad, consumers, would respond in the event of a price increase for the good or service in question, or if product standards were mandated to them. In these cases, they too face an investment/adoption decision, the prospect of incurring a fixed up-front cost to reduce long term dependence on a more expensive commodity. Their willingness and ability to do this will depend on the (long term) credibility of the price adjustment or policy, their purchasing power, and technology choices available to them.

**Figure 2.1: The Policy Response Triad**




Within the universe of policy responses, the three areas A, B, and C represent fundamentally different adjustment mechanisms. In region B, firms absorb most of the adjustment with a combination of price increases and investments in more efficient technology. Households are relatively insensitive to the price changes, and their demand patterns change relatively little, as was the case, for example, with recent oil price increases and rising home construction costs over the recent low interest rate cycle. In circumstances like this, demand driven sectors like electricity, refined

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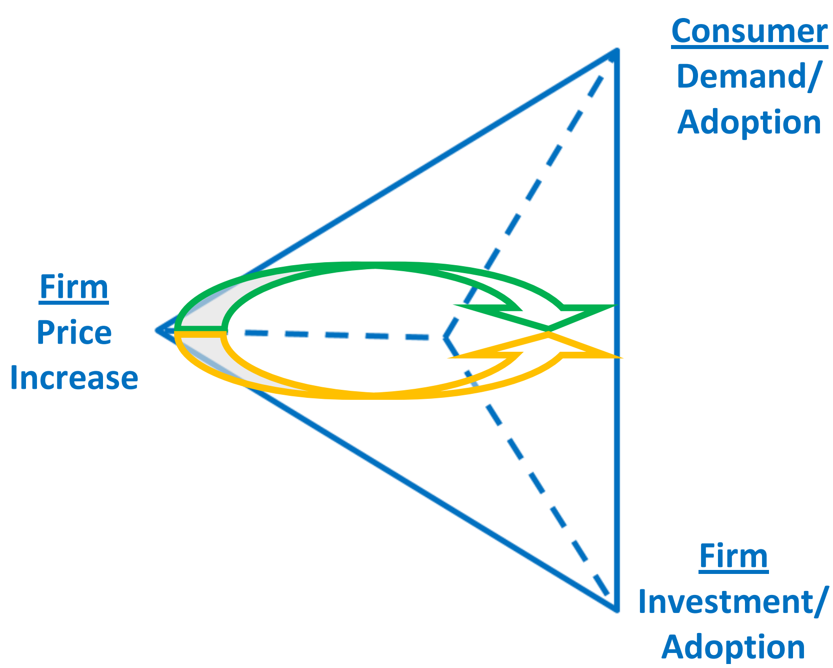
petroleum, and cement are more likely to maintain stable output trends and long term profitability, largely through passing on increased cost (left side of region B), efficiency improvements (right side) and combinations of these. Because, for the first-tier emitting industries, GHG efficiency is largely about energy efficiency, the long term savings for firms from technology adoption could be substantial if energy prices trend higher. In this context, cap and trade policies promise a double dividend.

Sections A and C imply more significant demand side adjustment, with more uncertain effects on statewide output, employment, and incomes. To the extent that households adopt efficiency improving technologies (cars, appliances, etc.), they can offset rising prices (A) or actually save money (C) to stimulate other forms of consumption. In the CAT scenario analysis (Roland-Holst:2006A), for example, induced household efficiency gains from mandatory standards (e.g. Pavley) produced significant personal energy savings. These were then reallocated to other consumption and, because this was more likely to be on in-state goods and services, GSP and state employment were stimulated.

**Figure 2.2: Structural Transition**



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Ultimately, all three components of structural adjustment will come into play. Generally speaking, the short run responses will be instigated by firms, since they are the original targets of the policy. Their first response, to the extent markets permit, will be to raise prices. As time passes, they will migrate (Figure 2.2, yellow arrow) toward new technology that enables their industry to return to competitiveness. This process, enshrined in the economic theories of competition, will arise from a combination of firm entry and adoption by incumbents to compete against or even deter such entrants. The speed by which competitive conditions are restored depends critically on the initial competitive conditions. If markets are too concentrated or entry barriers too high, this component of structural transition could proceed very slowly.

Meanwhile, consumers will respond to the initial price increase in two stages. In the short term, they can be expected to engage in demand smoothing, absorbing higher prices temporarily to prevent sudden changes in lifestyle. If price changes persist, however, this will be followed by decisions to change consumption patterns, including adoption of technologies that reduce dependence on higher priced goods (Figure 2.2, green arrow). The combination of these two trends yields the basic structural transition arising from cap and trade, the introduction of new private costs that more fully account for public costs of climate change risk.

## 2.2. Price Effects

To what extent can firms pass on the cost of regulation? This depends almost completely on the degree of their market power, sometimes called monopoly power. Clearly firms have a strong incentive to do this, since it would be a most economical way of neutralizing regulatory cost with no changes in operations or management practices. Of course their ultimate profit and output conditions are unlikely to remain neutral, since consumers will react in some way to a price pass through.

In any case, history can give us some guidance about pass through from production costs to prices even if the information is only inferential. In the cement industry, as in most emission-intensive industries, energy costs are a prominent or even dominant

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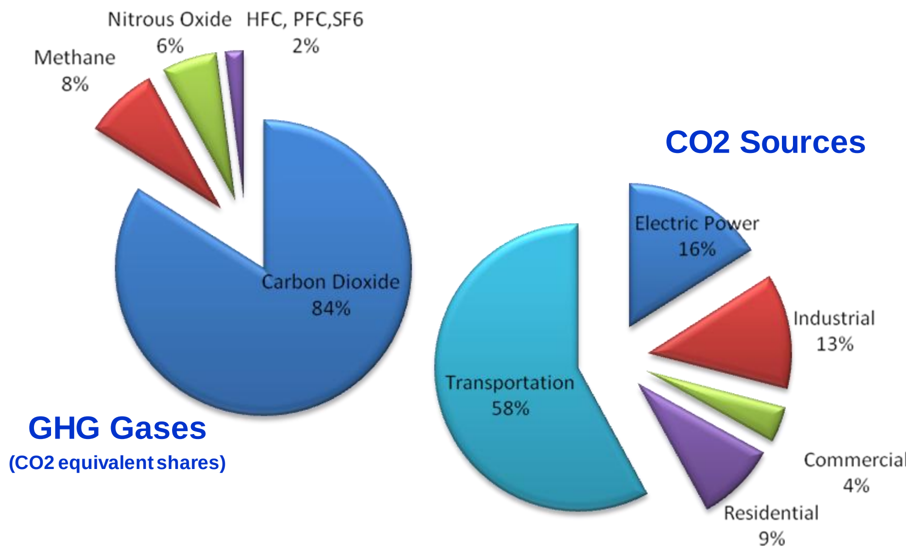
cost of production. This is quite apparent at the aggregate level in California (Figure 2.3), where we see that CO2 dominates GHG emissions and is itself a result of using carbon energy technologies for transportation, electricity production, heating, etc.

**Figure 2.3: Greenhouse Gases and Energy Use in California**




When energy prices increase, the market power of these firms is tested in their ability to pass along the cost increases, "sterilizing" an adverse profit effect. In the case of cement, natural gas is the dominant fuel source, and we can examine the historical correlation between LNG prices and cement prices for inference about the potential for pass through. Figure 2.4 plots the two variables against each other over the period 1970-2000, and a strong positive correlation is readily apparent.

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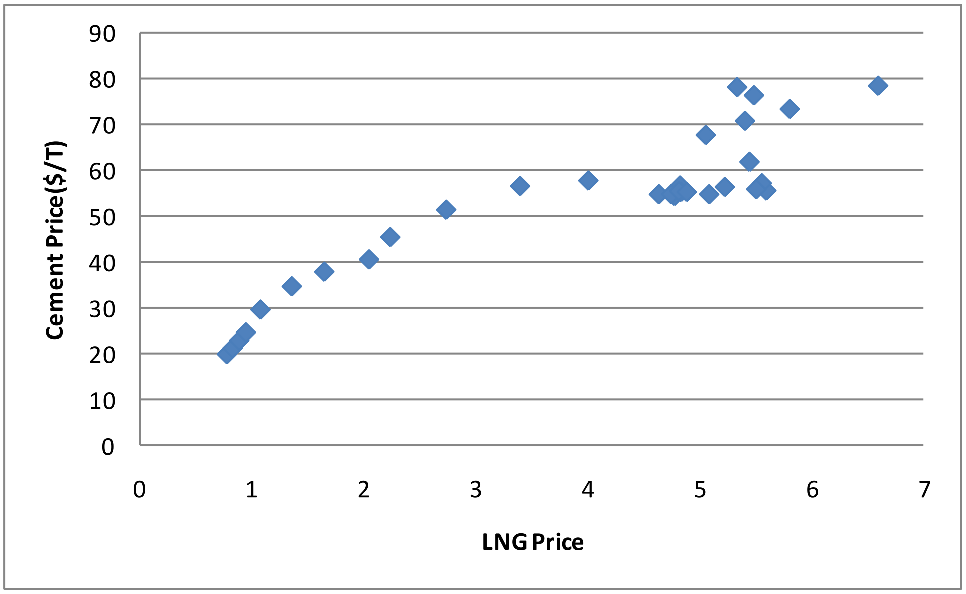
**Figure 2.4: National Cement and LNG Prices, 1970-2000**




To characterize this relationship more precisely, we regressed Cement prices against LNG prices, both in logarithmic form, and the results are presented in Table 2.1 summarizes the results. The relevant estimate is labeled the Coefficient of the X variable, which in this case denotes the historical elasticity of Cement prices with respect to LNG prices. This estimate indicates that, in percentage terms, Cement prices have risen at about half the rate of LNG prices over time. This percentage is larger than LNG's cost share in Cement production, and significantly so. Thus it appears that, were other conditions to remain constant over the period considered, Cement producers would be able to offset most or all energy price increases by passing them on to consumers. We know, however, that other cost components in Cement have risen steadily over time, so this elasticity is an over-estimate of LNG price effects on the sector under consideration. We still concluded, however, that a significant degree of market power and pass through is possible in this sector.

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**Table 2.1: Cost Price Elasticities for LNG and Cement, 1970-2000**

| *Regression Statistics* | |
|---|---|
| Multiple R | 0.96 |
| R Square | 0.91 |
| Adjusted R | 0.91 |
| Standard E | 0.05 |
| Observatio | 31 |

ANOVA

| | *df* | *SS* | *MS* | *F* |
|---|---|---|---|---|
| Regressior | 1 | 0.77 | 0.77 | 308.45 |
| Residual | 29 | 0.07 | 0.00 | |
| Total | 30 | 0.84 | | |

| | *Coefficients* | *tandard Err* | *t Stat* | *P-value* |
|---|---|---|---|---|
| Intercept | 1.42 | 0.02 | 79.13 | 0.00 |
| X Variable | 0.53 | 0.03 | 17.56 | 0.00 |

Elasticity estimation supports an empirical argument for cost pass through, but economic theory describes it as the result of combined supply and demand conditions. To compare this perspective, consider the examples in Figure 2.5 below, which depict supply and demand curves in the presence of a fixed increase to industry marginal cost (MC->MC'). When the supply curve on the right shifts upward, consumers and firms share the burden of increased cost (areas C and F). On the other hand, when supply is demand driven and highly elastic, as on the left, consumers bear all the increased cost.

Using the case of the Cement industry again, Figure 2.6 plots national output against inflation adjusted prices over the thirty year period 1970-2000. These figures suggest very strongly that Cement is a demand driven industry, and that the incidence of cost shocks can be passed on to consumers.

Thus we see from two perspectives that cost pass through to prices can occur, at least in the short run. In the face of process related cost shocks such as GHG regulation then, it is reasonable to expect firms to increase prices until they can make the efficiency improvements needed to return to competitiveness. Consumers will then react according to their short run demand elasticity. This could mean they are

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unresponsive in the short run, either because the price increase is not credible in the long term or they want to smooth consumption while planning technology adoption. In the longer term, if prices remain high they will contribute to structural transition by shifting consumption away through increased efficiency or substitution. Meanwhile, competitive firms will be shifting industry technology through their own structural transition, including firm entry, exit, and incumbent investments in more efficient technology. As the fixed costs of these investments and disinvestments are made, industry average costs will come back down toward a longer term equilibrium value, and some demand will be restored.

In a world of innovation and efficient capital markets, this structural transition can happen in a matter of a few years. If cap and trade policies are phased to take account of this, the adjustment process can be relatively smooth. For all this to work, both stakeholders and policy makers need reliable information about all these adjustment components. In this section, we use scenario analysis with the BEAR model to give indications about the magnitude and incidence patterns of structural transition, as it would arise from a cap and trade GHG mitigation regime.

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**Figure 2.5: Cost Pass Through under Alternative Supply Conditions**

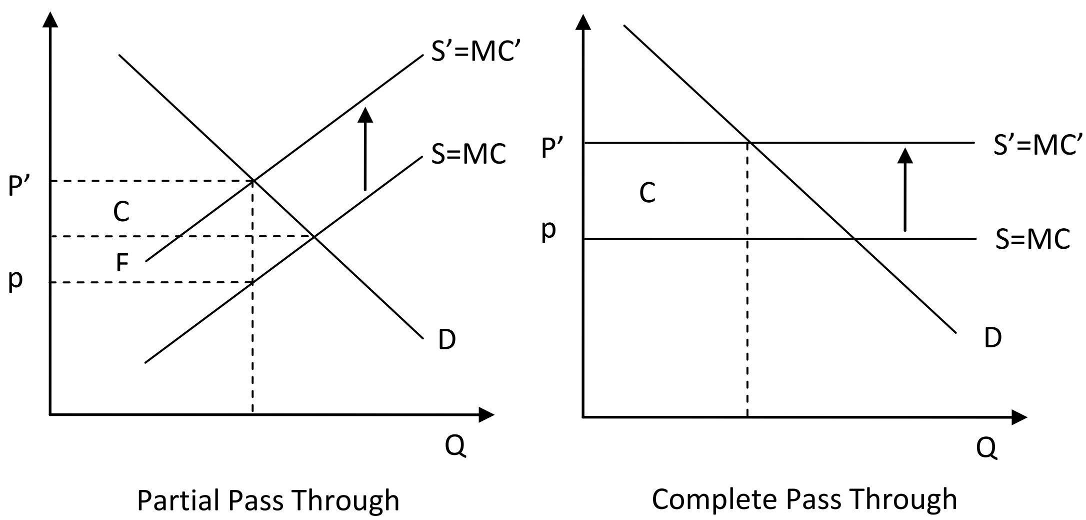
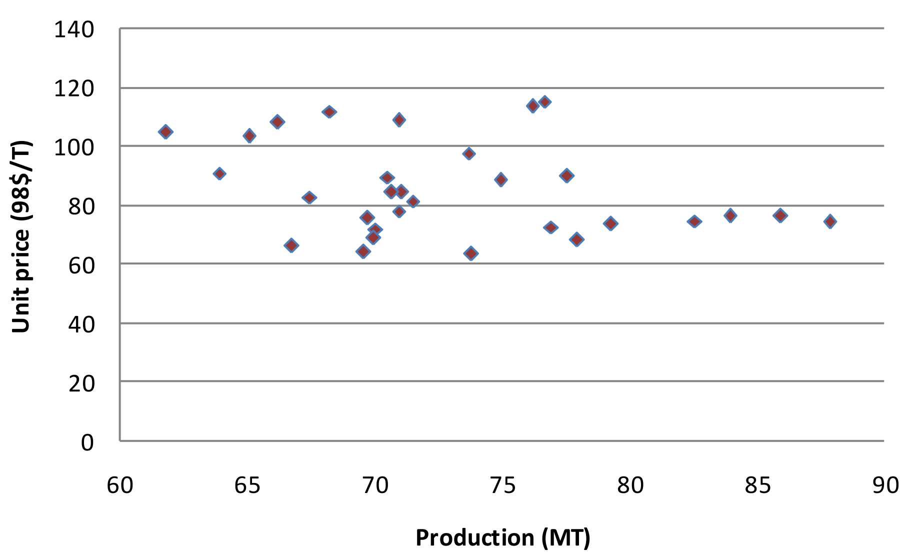



**Figure 2.6: Cement Industry Supply, 1970-2000**



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## 2.3. Scenarios and Results

In this section, we present a series of policy scenarios for climate action and discuss their implications for economic growth and structural transition of the California economy. In particular, we use the BEAR model for a more detailed assessment of California's cap and trade initiative, examining the interplay of each of the three components of structural transition discussed above (Figure 2.1). Unlike engineering and partial equilibrium analyses of environmental policies, this approach elucidates the interactions of firms and consumers across a spectrum of the state's economic activities and markets, where agents have a wider scope of choice and their extensive indirect linkages to other economic activities can be taken into account. The model also operates at a high level of detail to avoid aggregation bias that can mask spillover effects between sectors, stakeholders, and winners and losers.

The scenarios discussed here have already been studied in terms of aggregate economic effects in Roland-Holst (2006), but the present analysis goes deeper into the industry, factor market, and household effects of climate action policies like the cap-and-trade scheme considered here, using the BEAR model's detailed specification to better understand the complex patterns of structural incidence arising from these policies. As in the aggregate study, seven scenarios, summarized in Table 2.2, are evaluated.

The CAT scenario reflects a package of climate action initiatives recommended to the Governor by CalEPA in January, 2006. To these are added a cap-and-trade scheme with progressive sector inclusion (Table 2.4). In scenarios 2-5, permits are auctioned and firms adjust to the cap from their own resources. This approach increases the likelihood of adapting by passing on higher costs to consumers. In the last two scenarios, firms are allowed rebates of their permit costs if these are reinvested in efficiency enhancing new technology. The result is endogenous technical change that alters the structure of production toward higher efficiency, offsetting the adjustment costs for producers, consumers, and the economy as a whole.

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**Table 2.2: Policy Scenarios for Climate Action**

1. Baseline (no emission reduction target) [1]
2. 8 CAT policies (direct regulation) [2}
3. CAT policies plus emission cap to meet remainder of 2020 target
    a. Industries in Group 1 covered by an aggregate cap [3]
    b. Industries in Groups 1 and 2 covered by an aggregate cap [4]
    c. Industries in Groups 1, 2 and 3 covered by an aggregate cap [5]
4. 8 CAT policies plus emission cap on industries in Groups 1, 2 and 3 with revenues recycled into innovation investment [6]
5. 8 CAT policies plus emission cap on all emitting industries with revenues recycled into innovation investment [7]

## 2.4. Simulation Results

Aggregate impacts of the above scenarios have already been discussed in Roland-Holst (2006b), and are reproduced here only for convenience. Table 2.3 summarizes the variables of primary interest, GHG emissions, statewide real GSP and employment growth. Results are displayed as percentage changes with respect to the Baseline (scenario 1) in the final year (2020).

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**Table 2.3: Macroeconomic Impacts**

| | Scenario 2 CAT | 3 Group1 | 4 Group12 | 5 Group123 | 6 G123Gr | 7 AllIn |
|---|---|---|---|---|---|---|
| **Total GHG*** | -13 | -28 | -28 | -28 | -28 | -28 |
| **Household GHG*** | -32 | -32 | -32 | -32 | -31 | -30 |
| **Industry GHG*** | -3 | -26 | -26 | -26 | -26 | -27 |
| **Annual GSP Growth*** | 2.4 | 2.4 | 2.4 | 2.4 | 3.1 | 4.7 |
| **Employment*** | .10 | .06 | .08 | .08 | .44 | 1.07 |
| **Jobs (thousands)** | 20 | 13 | 16 | 17 | 89 | 219 |
| **Percent of GHG Target** | 47 | 101 | 100 | 100 | 100 | 100 |

*Percent change from Baseline scenario in the year 2020.

The CAT scenario (2) was discussed in detail in Roland-Holst (2006a) and it suffices here to note only its general characteristics. Implementing just eight leading CAT policies has the potential to achieve about half of the California's targeted 2020 emissions reductions, while at the same time stimulating state output and employment. The economic stimulus results from the dynamic gains that arise when demand is diverted to more California-intensive expenditure as energy efficiency saves money for households and industry, promoting state economic growth. This result can be contrasted with a static Ricardian model, where international resource constraints impose offsetting terms-of-trade adjustments on import substitution. In an open ended dynamic scenario, retained state expenditures have multiplier effects that compound domestic income, saving, and employment growth. [2]

Expanding beyond the CAT scenario, we examine a progressively larger coverage of a cap on emissions designed to make up the remaining reduction in emissions . The three industries in Group 1 are frequently identified as the core sectors for a GHG cap. Our results for Scenario 3 suggest, however, that these sectors almost certainly should not bear the burden of adjustment to the 2020 targets alone. Indeed, BEAR estimates of their baseline GHG emissions for 2020 are about 173MMT, while hitting

[2] The dynamic benefits of energy import substitution have been corroborated by the Climate Action Team in its in-house economic analysis of these policies. Compare also RFF et al (2007). Other authors have challenged these findings (e.g. Stavins et al:2007), but their concerns relate mainly to data quality and meager evidence for alternative outcomes has been provided to date.

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the target would require about 90MMT in emission reductions, an implied annual reduction in sectoral intensity of over 3.5% (see Table 4.3). For this reason, the scenario appears infeasible on a sustained intensity reduction basis, resulting in slightly lower annual real GSP growth and employment statewide.

When the scope of industry coverage is expanded to include the nine industries in Group 2, Scenario 4, the results are much more encouraging. In this scenario, the nine sector group could meet the governor's 2020 targets with less than 3% annual improvements in average emission intensity.[3] While this seems a feasible aggregate objective, however, it is important to recognize that the adjustment burden will fall differently on different sectors, depending on their initial intensity and share of the mitigation they must achieve. One of the advantages of detailed simulation models like BEAR is that they capture these important compositional effects, and in Table 4.3 we see how increasing scope diffuses the burden of adjustment.

In this scenario, the nine sectors responsible for meeting the target will have to reduce emission intensity by up to 3.65% per annum, sustaining this over a nine year period. This level, too, will be difficult to sustain. Even when scope is extended to all industries, Scenario 5, nine year average annual efficiency gains of over 2.9% would be needed.

The main alternative to this would be extending regulation to services and mobile sources or to orchestrate the present scenario with other GHG policies, yet the all-inclusive Scenario 7 indicates this would still require more than 2% annual mitigation and the administrative feasibility of such a program is very doubtful.

The results in Scenarios 5-7 results are broadly consistent with what is assumed in some other policy analyses. For example, the President's climate change policy for voluntary GHG emission intensity reductions stipulates 2% mitigation per year for ten years (Abraham, 2004), and this goal is approximately in line with historical national trends. California itself has experienced approximately a 2% decline in GHG intensity from 1990-2000 (Climate Action Team, 2006). It must be recalled, however, that these

[3] Note in Table 4.3 that several sectors have much higher annual intensity reductions, some over 4.5%, because of legacy effects from being targeted by CAT policies.

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scenarios include some mandatory (direct regulation) CAT policies. The clear message is that California must take policy initiative to achieve these overall levels of abatement.

From Scenarios 2 - 5, we can draw a few salient inferences. Firstly, industry-oriented GHG mitigation needs to be relatively inclusive if the adjustment burden is to be manageable. Second, this category of policy needs to be coordinated with other substantial commitments to GHG efficiency (e.g. CAT regulatory policies). In the case considered here, where an inclusive industry policy is combined with other GHG regulatory initiatives, we find that industry must still improve energy efficiency and GHG gas intensity substantially. Although the implied rates of improvement are probably feasible, they appear to be significantly outside the range of voluntary compliance. The apparent need for more determined and directed mitigation schemes brings us to Scenarios 6 and 7.

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**Table 2.4: Alternative Industry Emission Groups**

1. **Group 1: First-tier Emitters**

| | |
|---|---|
| A04DistElc | Electricity Suppliers |
| A17OilRef | Oil and Gas Refineries |
| A20Cement | Cement |

2. **Group 2: Second-tier Emitters**

| | |
|---|---|
| A01Agric | Agriculture |
| A12Constr | Construction of Transport Infrastructure |
| A15WoodPlp | Wood, Pulp, and Paper |
| A18Chemicl | Chemicals |
| A21Metal | Metal Manufacture and Fabrication |
| A22Aluminm | Aluminium Production |

3. **Group3: Other Industry Emitters**

| | |
|---|---|
| A02Cattle | Cattle Production |
| A03Dairy | Dairy Production |
| A04Forest | Forestry, Fishery, Mining, Quarrying |
| A05OilGas | Oil and Gas Extraction |
| A06OthPrim | Other Primary Activities |
| A07DistElec | Generation and Distribution of Electricity |
| A08DistGas | Natural Gas Distribution |
| A09DistOth | Water, Sewage, Steam |
| A10ConRes | Residential Construction |
| A11ConNRes | Non-Residential Construction |
| A13FoodPrc | Food Processing |
| A14TxtAprl | Textiles and Apparel |
| A16PapPrnt | Printing and Publishing |
| A19Pharma | Pharmaceuticals |
| A23Machnry | General Machinery |
| A24AirCon | Air Conditioner, Refrigerator, Manufacturing |
| A25SemiCon | Semiconductors |
| A26ElecApp | Electrical Appliances |
| A27Autos | Automobiles and Light Trucks |
| A28OthVeh | Other Vehicle Manufacturing |
| A29AeroMfg | Aeroplane and Aerospace Manufacturing |
| A30OthInd | Other Industry |

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### 2.4.1. *Electric Power Sector*

Our results indicate that the electric power sector can be a primary contributor to GHG reductions in the state, but for this sector policy choice and implementation will make a critical difference to the outcomes for all stakeholders. If a less inclusive (First-tier) cap is chosen, this sector will have to achieve emission reductions averaging over 4% per year over a decade. This is a very ambitious target, and can only be met with a combination of outlays for pollution permits in the short run and capacity shifting to more efficient sources in the long run. Both these activities will escalate costs, and we estimate that electricity prices could be nearly 20% higher by 2025 as a result. This kind of price escalation will increase costs for electricity users, directly in consumption, and indirectly in the form of expenses for induced technology adoption.

**Table 2.5: Structural Adjustment in the Electric Power Sector (percent change from Baseline in 2020)**

| | CAT | G1CAT | G12CAT | G123CAT | G123RR | GAll |
|---|---|---|---|---|---|---|
| **Emissions** | 0% | -51% | -39% | -30% | -32% | -25% |
| **Price** | 0% | 20% | 9% | 5% | 1% | -1% |
| **Output** | 0% | -8% | -4% | -2% | 0% | 2% |
| **Imports** | 0% | 11% | 5% | 3% | 1% | 0% |

As the simulation results in Table 2.5 indicate, structural adjustment in the sector could be quite dramatic. If only the first-tier emitters were targeted for a cap and trade system, by 2020 Electric Power will have to reduce emissions by half. The ensuing adjustments would increase retail price pressure by up to 20%[4], while state industry output falls by 8%. At the same time, rising in-state cost/price conditions invite import penetration, and electricity imports rise by 11%.

[4] It should be borne in mind that this price adjustment assumes market clearing prices are accepted by regulatory authorities. Administered prices at other levels would propagate distortions elsewhere.

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More inclusive caps will defray this adjustment burden to other sectors, prices, and commodity classes, but without investment incentives the overall "new" cost of the cap and trade scheme will impose efficiency costs on the state economy. The key to averting this is promotion of innovation and technology adoption, as can be clearly seen in the last two scenarios. When cap and trade policies provide rebates for investment and adoption of more efficient technology, the result is neutralization cost/price inflation and sustained growth.

Having said this, it is important to note that structural change will have more detailed costs, even when industrywide and statewide nets benefits are realized. To see this, note the dispersion of efficiency levels in the states, existing generation capacity, as depicted in Figure 2.7 for the largest generation sites, together representing half of California's capacity. Even within the natural gas generation cohort, observed efficiency levels can vary by a factor of two. Clearly, the Load Serving Entities (LSEs) will have strong incentives to shift their portfolios across these sources (from right to left) as they come under increasing GHG regulation. This kind of shifting will drive up capacity use and costs from the more efficient sources, but in any case is likely to be a first alternative to new investments in the short and medium term. The exact composition of this shift would be very useful to anticipate, both for the sake of private stakeholders and public agencies who might be able to mitigate the ensuing adjustment costs. It cannot, unfortunately, be estimated from publicly available information.

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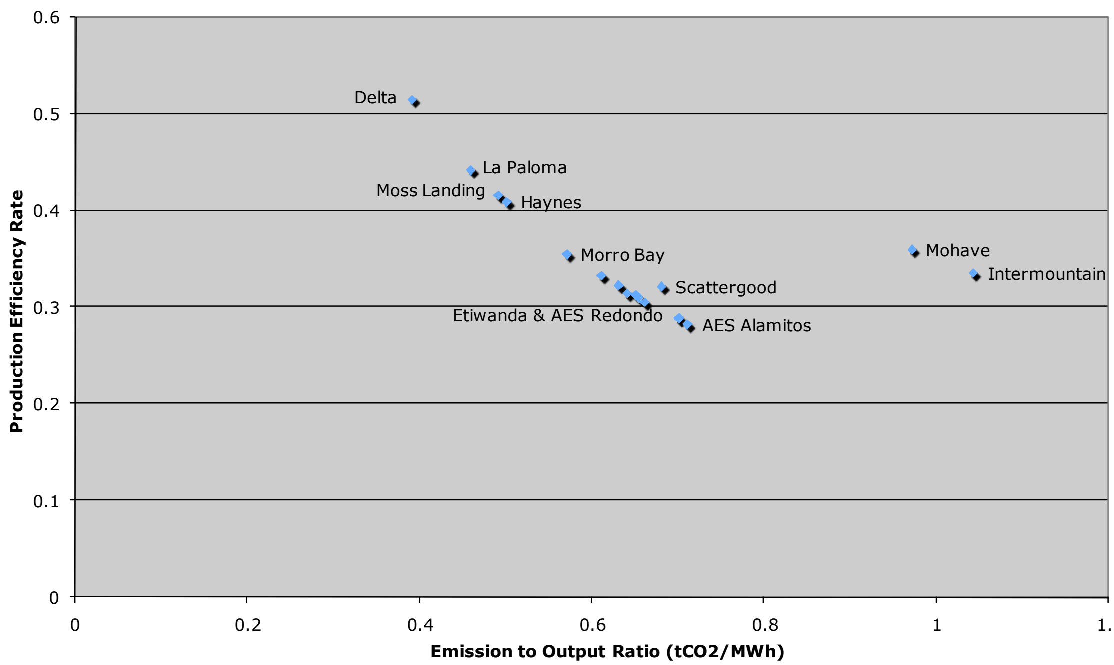
**Figure 2.7: Emission Rates and Production Efficiency**




### *2.4.2. Cement*

The Climate Action mitigation policies in the cement sector can make modest but important contributions to reducing statewide emissions. If all the above measures are adopted, about 2.5% of total emissions can be eliminated on an annual basis. At the same time, the direct and indirect macroeconomic and industry level effects of the first four polices are small but negative. In the cap and trade scenarios, we see a classic example of the challenge posed by structural transition. If incumbent firms in the industry merely pass on their increased cost, sectoral output and employment will be adversely affected. If cap and trade phase-ins include incentives for investment and technology adoption, both the sector and the state economy will again benefit.

Table 2.6 outlines final year real adjustments for the Cement industry, and these results significantly resemble Electric Power. As with the latter industry, significant GHG mitigation translates into notable cost/price pressure, but here less than one third the percentage increase, and only a 2% induced decline in the trend for industry

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output. Nonetheless, import penetration increases and export competitiveness is undermined by the new costs associated with the cap and trade system.

Greater sector inclusiveness in the cap reduces the adjustment burden for Cement, but not as much as it does for Electric Power. This is because fuel costs are a larger percent of total costs for Cement, and thus permit costs induce greater mitigation even when the cost of permits declines with larger and more diverse program coverage.

**Table 2.6: Structural Adjustment in the Cement Sector (percent change from Baseline in 2020)**

| | CAT | G1CAT | G12CAT | G123CAT | G123RR | GAll |
|---|---|---|---|---|---|---|
| **Emissions** | -3% | -55% | -43% | -34% | -35% | -28% |
| **Price** | 0% | 6% | 3% | 2% | 0% | -1% |
| **Output** | 0% | -2% | -1% | -1% | 0% | 2% |
| **Imports** | 0% | 11% | 5% | 3% | 0% | -1% |
| **Exports** | 0% | -5% | -2% | -1% | 0% | 2% |

An important unresolved issue in this sector, one that is not incorporated in these scenarios, concerns the potential to blend cement  with fly ash, reducing the energy intensity of its processes and significantly offsetting this sector's carbon liability. At the present time, the industry's largest individual customer, a public agency, is undecided about whether or not blended cement will meet its needs. This deadlock poses an important obstacle to the industry's strategy for meeting the state's own environmental objectives, and it also denies the cement market and essential precedent of adoption.

It may also be worth noting that, even in the worst case scenario considered, cost escalation in this sector appear unlikely to threaten plant viability. By historical standards, the cement sector has endured much greater cost escalations from its primary input, energy fuels.

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### 2.4.3. *Petroleum Refining*

Oil refining is a major part of the California economy, both in terms of output and employment, but also in terms of demand for its final products. The refining sector accounted for 5% of California manufacturing sales in 1997, and the sector employs nearly 10,000 people.[5] On the demand side, California is the largest consumer of gasoline in the U.S. (11.3% in 2004), and second largest consumer of the country's jet fuel (17.7%); 40% of California's 2003 energy consumption was used for transportation.[6]

**Table 2.7: Structural Adjustment in the Petroleum Refining Sector (percent change from Baseline in 2020)**

| | CAT | G1CAT | G12CAT | G123CAT | G123RR | GAll |
|---|---|---|---|---|---|---|
| **Emissions** | 0% | -46% | -36% | -28% | -30% | -23% |
| **Price** | 0% | 6% | 3% | 2% | 1% | -2% |
| **Output** | 0% | -2% | -1% | -1% | 0% | 2% |
| **Imports** | 0% | 3% | 1% | 1% | 1% | 0% |
| **Exports** | 0% | -5% | -2% | -1% | -1% | 2% |

Cap and trade effects in this sector are complex because of the diversity of its product stream, relatively low demand elasticities, and its pervasive linkages across the economy. In addition to its direct effluent potential, this sector is the primary channel for carbon fuels to reach the transport sector, so there are important feedback effects to refining from any measures that increase fuel efficiency elsewhere in the economy.

Despite its complexity, the industry results for petroleum refining aggregate to resemble those of a typical energy-intensive manufacturing sector. On an average basis, however, the experience of this sector is intermediate between that of the two already considered. Again we see the potential challenge and opportunity posed by structural transition. If incumbent firms must bear their entire share of the cost of a cap and trade scheme, their prices can be expected to rise 6% by 2025, with

[5] Ernst Worrell and Christina Galitsky, 2004, "Profile of the Petroleum Refining Industry in California," LBNL-55450.
[6] Energy Information Administration (EIA) State Energy Profiles, online at: http://tonto.eia.doe.gov/state/state_energy_profiles.cfm?sid=CA#Con.

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predictable effects on demand and supply. If instead they are part of an investment oriented policy package, price effects will be negligible.

Meanwhile, the diversity of technology in this sector means that structural transition may create winners and losers among incumbent firms. This will depend upon the market power of individual refiners, as well as their ability to take advantage of investment incentives.[7]

### 2.4.4. *Chemicals*

The chemical sector will be discussed briefly here as an instructive example of a second-tier emissions source. While the experience some contraction under the first-tier scenario because of energy price escalation (Table 2.8), they are negligibly affected by adapting to inclusion in a cap and trade scheme. The reasons for this are many. A high level of competitiveness in this sector limits price pass through, high autonomous investment and technology adoption rates, and extensive scope for own efficiency improvements all support a relatively smooth adjustment process. Indeed, this sector's own innovation capacity makes it poised to benefit from the incentive oriented policies in the last two scenarios, stimulating both in-state output and export competitiveness for California chemicals.

**Table 2.8: Structural Adjustment in the Chemical Sector**
**(percent change from Baseline in 2020)**

| | CAT | G1CAT | G12CAT | G123CAT | G123RR | GAll |
|---|---|---|---|---|---|---|
| **Emissions** | 0% | -1% | -42% | -33% | -33% | -26% |
| **Price** | 0% | 0% | 0% | 0% | -1% | -2% |
| **Output** | 0% | -1% | -1% | 0% | 2% | 3% |
| **Imports** | 0% | 0% | 0% | 0% | 0% | 1% |
| **Exports** | 0% | 0% | 0% | 0% | 1% | 3% |

[7] It should be emphasized that this sector is under very strict regulation regarding new capacity creation, and thus its ability to adopt new technology, even if the objective is greater energy/GHG efficiency, is open to question.

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As explained in more detail below, chemicals play an important role in statewide emissions, but they do so as much because of their demand for energy intensive products (e.g. electricity) as because of direct GHG effluent from the sector itself. Chemicals are the second largest energy consumer among the state's manufacturers, and for this reason mitigation potential from energy efficiency is considerable. While the industry as a whole appears to have structural flexibility, it is reasonable to expect winners and losers to emerge as competitive forces bring forward new technologies and the resultant cost savings confer strategic advantage on early adopters. Unfortunately, publically available information on plant-specific cost/technology structures is quite limited, making it impossible to estimate within-sector tradeoffs.

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# 3. ELECTRICITY

Accounting for 16% of California registered $CO_2$ emissions, the electric power sector will play an essential role in meeting the state's GHG targets. To better understand this essential strategic sector, we consider it in two parts. First, we discuss distributors of electricity, an industry dominated by three Load Serving Entities (LSE's) and a large and diverse group of smaller electricity distributors. Demand by the LSE's ultimately determines patterns of emissions from electric power generation, so they are likely targets of any policies to mitigate emissions from power generation, and their behavior and contracting activities need to be understood. After an overview of the distributors, we move back up the electricity supply chain to the generating technologies themselves. Here plant characteristics will be the primary determinants of structural adjustment, with more efficient plants in a better position to adapt to regulatory change in a cost effective manner.

## 3.1. Modelling the Behavior of Load Serving Entities

A standard economic simulation framework models industrial and service activities with one representative firm per sector, assuming production arises from neoclassical assumptions of profit maximization and perfect competition. For a variety of reasons, this paradigm is not an accurate or even reliably approximate reflection of the structure and conduct of the electricity distribution sector. When elaborating a standard economic model for this purpose, three salient characteristics need to be taken into account:

1. Larger LSE's are not firms are representable by a single homogeneous production function, but distinct entities with delineated markets who draw their supply from a portfolio of generation technologies.

2. Output prices in this sector are rigid.

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3. Because of the economic costs of supply uncertainty, this sector maintains substantial excess capacity.

Schematically, the market structure of this sector is described in Figure 3.1 below. There are three leading LSEs, Pacific Gas and Electric, Southern California Edison, and San Diego Gas and Electric. The fourth LSE represents an aggregate of all other electricity distributors. Each of these hires its own factors of production (labor capital) and draws upon portfolio of in-state and out-of-state generation technologies, extracting electricity supply from them by direct ownership or contracts for delivery.

In response to the special characteristics listed above, the BEAR model adds special structural features for this sector. These include the following characteristics:

Individual firm specification for each of the four LSE's in Figure 3.1.

1. Fixed prices in a demand-driven market.

2. In the short run, LSE's choose the level of capacity utilization.

3. In the long run, LSE's choose capacity via investment and contracting.

The California electricity generation system is one of the largest contributors to greenhouse gas emissions in the state. In looking at the top tier producers (totaling 41% of California generation capacity[8]), it is apparent that California suppliers may be better able to adapt to forthcoming carbon restrictions. In today's California electricity industry, portfolio decisions by the LSE's have led to capacity that is significantly less carbon-intensive than national averages. As Figure 3.2 indicates, California electric power relies significantly less on coal, more on hydro and natural gas than does the nation as a whole (including California). Renewable technologies have also emerged more strongly in the state.

[8] http://www.energy.ca.gov/

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Figure 3.1: Schematic Structure of the Electricity Distribution Sector

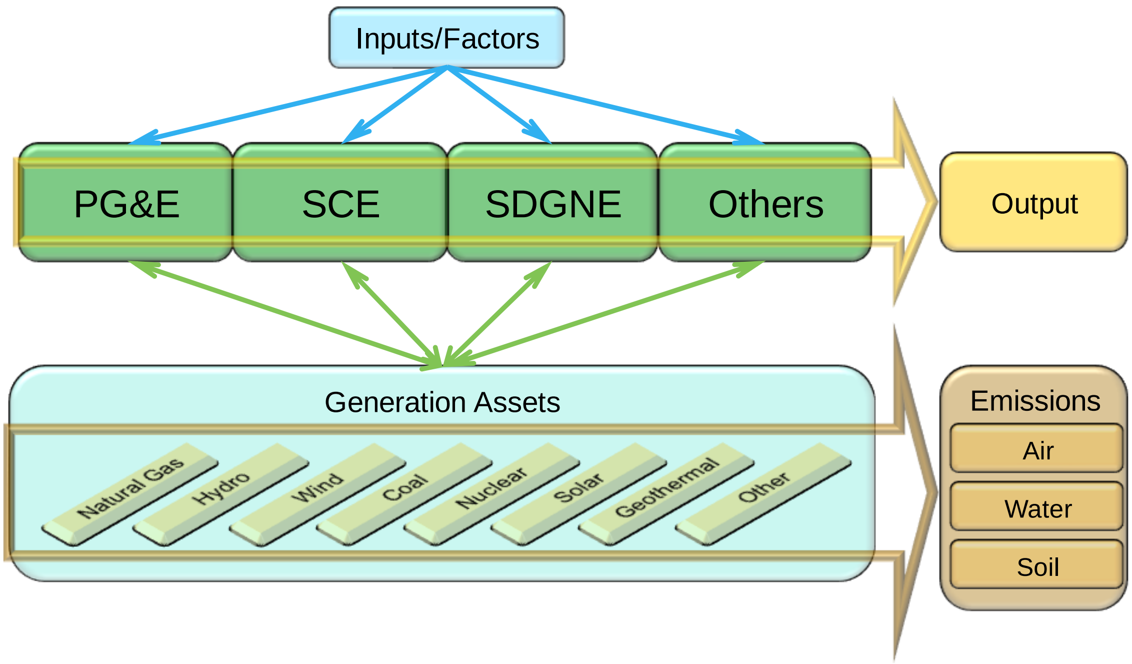
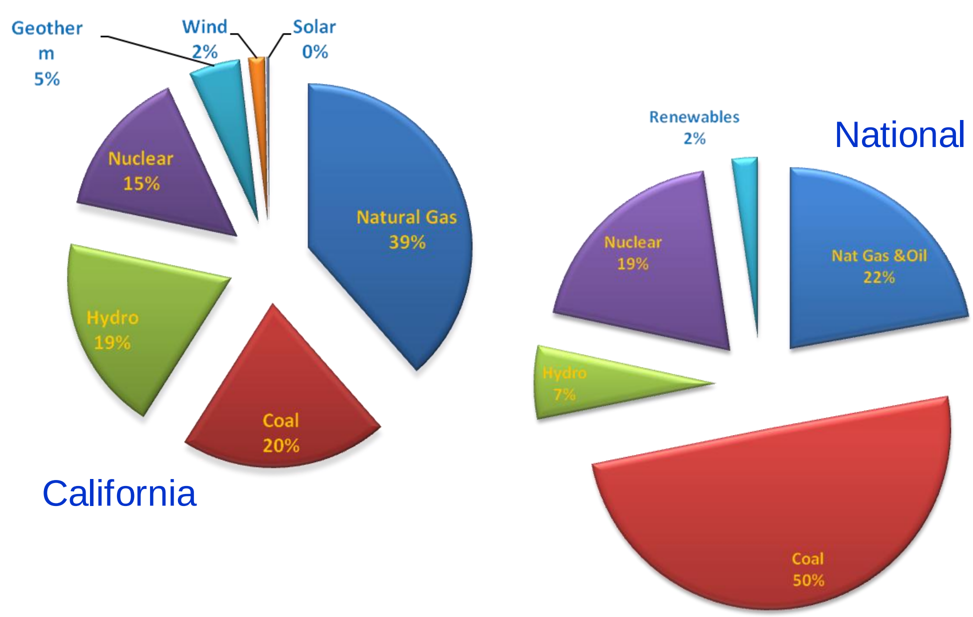



Figure 3.2: Technology Portfolios for Electric Power Generation



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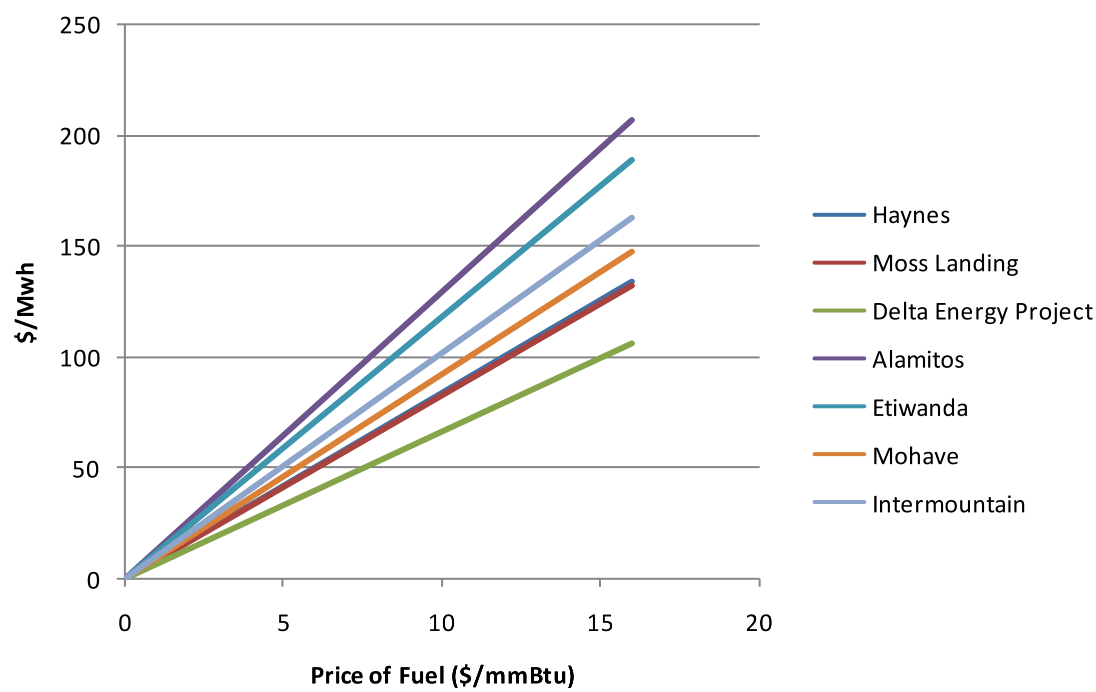
## 3.2. Power Generation at the Plant Level

This is not to say, however, that the electricity sector will not face significant obstacles. Many of California's critical electrical plants rely on older technologies that do not maximize fuel efficiency. Inefficient fuel utilization presents the source of greatest risk for survival of a plant in a cap-and-trade regulatory environment. This is because the average fuel cost of production ($/MWh) dominates marginal cost of production for each and every one of these plants. Their ability to produce and sell their output competitively, either to LSE's though contracts or for them if they are wholly-owned capital assets, depends critically on this. In a market facing rising fuel cost trends, inefficient fuel utilization magnifies average fuel cost pass through to marginal costs, intensifying diminishing profit margins (see Figure 3.3).

**Figure 3.3: Estimated Marginal Cost with Respect to Fuel Prices**




This is a subject we will discuss more deeply upon closer scrutiny of individual plants. We begin, however, with a general overview of the state's electric power generation

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sector. There are over 900 electrical generating facilities in California. About 20 large plants produce almost 50% of total output (Figure 3.4), and these larger plants will be the focus of the present study.

In particular, we reviewed 18 natural gas plants which provide 66% of California's electricity (including imports) and two coal plants, Mohave and Intermountain, located in Nevada and Utah respectively but are owned by Californian companies. Mohave and Intermountain both have historically been large contributors to California's electric power capacity. Mohave, however, closed down at the end of 2005 due to a court order (to clean up emissions or cease operation) issued in 1999. Intermountain, on the other hand, is still open but having difficulty finding utilities to buy its output. On December 13, 2006, Truckee Donner Public Utility District near Lake Tahoe voted to reject power from Intermountain Coal Plant. Generally speaking, despite low costs, coal plants seem to be on the decline when it comes to California consumer choice. The rest of the California plants are Natural Gas powered and quite diverse in their modernization level and preparedness for a carbon cap-and-trade system. A complete list of plants surveyed in this report is given in Table 2.1.

**Figure 3.4: Size Distribution of Electric Power Facilities, California**

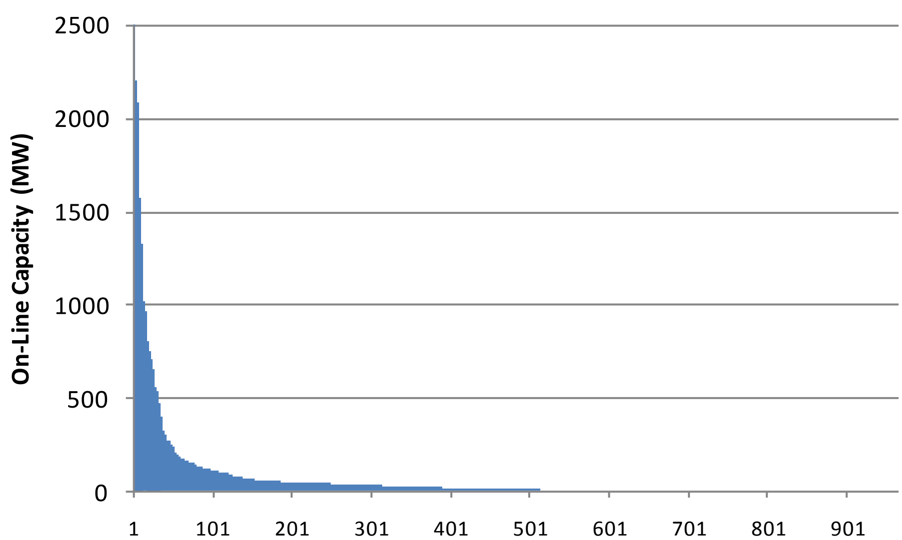


**Table 2.1: Top Tier California Electric Power Plants**

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| | Fuel Type | MW Capacity | Share of CA | CO2 Emissions | Share of Sector |
|---|---|---|---|---|---|
| **Moss Landing** | Nat. Gas | 2545 | 4.06 | 2,376,736 | 7.51 |
| **AES Alamitos** | Nat. Gas | 2087 | 3.33 | 974,950 | 3.08 |
| **Intermountain** | Coal | 1640 | 2.62 | 15,182,583 | N/A |
| **Mohave** | Coal | 1636 | 2.61 | 10,770,045 | N/A |
| **Haynes** | Nat. Gas | 1570 | 2.51 | 1,875,177 | 5.92 |
| **Ormond Beach** | Nat. Gas | 1492 | 2.38 | 341,390 | 1.08 |
| **Pittsburg** | Nat. Gas | 1332 | 2.13 | 449,662 | 1.42 |
| **Redondo Beach** | Nat. Gas | 1317 | 2.10 | 300,901 | 0.95 |
| **Morro Bay** | Nat. Gas | 1021 | 1.63 | 189,495 | 0.60 |
| **La Paloma** | Nat. Gas | 968 | 1.55 | 2,164,683 | 6.84 |
| **Huntington Beach** | Distillate Oil | 880 | 1.41 | 1,000,720 | 3.16 |
| **Delta Energy Cntr.** | Nat. Gas | 861 | 1.38 | 2,257,632 | 7.13 |
| **Scattergood** | Nat. Gas | 803 | 1.28 | 773,854 | 2.44 |
| **Etiwanda** | Disillate Oil | 770 | 1.23 | 546,027 | 1.72 |
| **High Desert Power** | Nat. Gas | 750 | 1.20 | 1,572,707 | 4.97 |
| **Coolwater** | Nat. Gas | 726 | 1.16 | 247,314 | 0.78 |

The competitiveness of plants under the new system will hinge principally upon two factors, how well they minimize carbon output (measurable by the emission to output ratio tCO2/MWh) and maximize fuel efficiency rates. For the sake of discussion, we derive a competitiveness index (Fuel Efficiency ratio divided by the emission to output ratio) to rank Natural Gas fired plants in terms of adaptability to more stringent GHG emissions regulation. The same index can be used to rank coal-fired plants, however, ranks across plant time should not be compared due to differing price/mmBtu.

Table 2.2 presents the basic competitiveness estimates. A clear monotone trend suggests the near perfect correlation between fuel and emission efficiency, as well as the veracity of the underlying data. From the competitiveness estimates in Table 2.2 we see that these indexes can differ by a factor of three or four. This implies that significant adjustment patterns can be expected across these suppliers, either in terms of sales, technology renewal, or both. Of course there are many constituents to individual plant balance sheets, and other determinants of the their competitiveness. These include market access and conveyance costs, legacy capital and resource costs, and a variety of non-fuel variable costs of operating and maintaining plants.

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Unfortunately, information on these characteristics at the plant level is very difficult to obtain. However, industry averages of this information indicate that the ranges of non-fuel O&M costs we have estimated independently to bounded at about $2/MWh. As will become apparent below, this is negligible when compared to average fuel costs of production ($/MWh).

**Table 2.2: Emissions, Efficiency, and Competitiveness by Plant**

| Plant | Tons CO2/MWH | Efficiency | Competitiveness Index |
|---|---|---|---|
| **Delta Energy** | .39 | .52 | 1.32 |
| **La Poloma** | .46 | .44 | .97 |
| **Moss Landing** | .49 | .42 | .85 |
| **Haynes** | .50 | .41 | .82 |
| **Morro Bay** | .57 | .36 | .62 |
| **Coolwater** | .61 | .33 | .55 |
| **Ormond Beach** | .63 | .32 | .51 |
| **AES Huntington** | .64 | .31 | .49 |
| **Pittsburg** | .65 | .31 | .48 |
| **High Desert** | .65 | .31 | .47 |
| **Scattergood** | .68 | .32 | .47 |
| **Cabrillo/Encina Power** | .66 | .31 | .46 |
| **AES Redondo** | .70 | .29 | .41 |
| **Etiwanda** | .70 | .29 | .41 |
| **AES Alamitos** | .71 | .28 | .40 |
| **Mohave*** | .97 | .36 | .37 |
| **Intermountain*** | 1.04 | .34 | .32 |

Source:

*Coal used as primary fuel.

We now review a subset of the leading plants to give a general indication of the primary drivers of efficiency. Their basic cost data are summarized in Table 2.3 below.

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## Table 2.3: Estimated Plant Cost Data

| Name | Facility | Unit | Year in Service | Avg Fuel Price cts/MMBtu | Avg Fuel Price $/MWh | Fixed O&M $/kW | Non-fuel Var O&M $/MWh | Total O&M $M | Total O&M $/MWh | Capital $/kW |
|---|---|---|---|---|---|---|---|---|---|---|
| **AES Alamitos** | 315 | 1 | 1956 | 572.16 | 67.67 | 19.8 | 0.98 | 206.862 | 79.72 | 155.66 |
| **AES Alamitos** | 315 | 2 | 1957 | 572.16 | 67.67 | 19.8 | 0.98 | 206.862 | 79.72 | 155.66 |
| **AES Alamitos** | 315 | 3 | 1961 | 572.16 | 67.67 | 19.8 | 0.98 | 209.971 | 79.72 | 155.66 |
| **AES Alamitos** | 315 | 4 | 1962 | 572.16 | 67.67 | 19.8 | 0.98 | 210.030 | 79.72 | 155.66 |
| **AES Alamitos** | 315 | 5 | 1966 | 572.16 | 67.67 | 19.8 | 0.98 | 213.000 | 79.72 | 155.66 |
| **AES Alamitos** | 315 | 6 | 1966 | 572.16 | 67.67 | 19.8 | 0.98 | 213.000 | 79.72 | 155.66 |
| **Haynes Station** | 400 | 1 | 1962 | 641.93 | 69.89 | 13.7 | 2.3 | 151.303 | 81.59 | 214.05 |
| **Haynes Station** | 400 | 10 | 2005 | 510 | 36.72 | 15 | 2 | 8.625 | 40.43 | 214.05 |
| **Haynes Station** | 400 | 2 | 1963 | 641.93 | 69.89 | 13.7 | 2.3 | 151.303 | 81.59 | 214.05 |
| **Haynes Station** | 400 | 5 | 1966 | 641.93 | 69.89 | 13.7 | 2.3 | 152.933 | 81.59 | 214.05 |
| **Haynes Station** | 400 | 6 | 1967 | 641.93 | 69.89 | 13.7 | 2.3 | 152.933 | 81.59 | 214.05 |
| **Haynes Station** | 400 | 9 | 2005 | 510 | 36.72 | 15 | 2 | 8.625 | 40.43 | 214.05 |
| **Pittsburg Power Plant (CA)** | 271 | 5 | 1960 | 644.85 | 62.25 | 11.98 | 1.08 | 118.565 | 72.44 | 227.55 |
| **Pittsburg Power Plant (CA)** | 271 | 6 | 1961 | 646.73 | 62.25 | 11.98 | 1.08 | 118.624 | 72.44 | 227.55 |
| **Pittsburg Power Plant (CA)** | 271 | 7 | 1972 | 571.04 | 62.25 | 11.98 | 1.08 | 122.998 | 72.44 | 227.55 |
| **Ormond Beach Station** | 350 | 1 | 1971 | 574.84 | 59.99 | 18.14 | 0.98 | 150.526 | 73.24 | |
| **Ormond Beach Station** | 350 | 2 | 1973 | 574.84 | 59.99 | 18.14 | 0.98 | 151.143 | 73.24 | |
| **AES Redondo Beach** | 356 | 5 | 1954 | 573.27 | 62.54 | 19.8 | 0.98 | 85.673 | 81.49 | 184.43 |
| **AES Redondo Beach** | 356 | 6 | 1957 | 573.27 | 62.54 | 19.8 | 0.98 | 85.596 | 81.49 | 184.43 |
| **AES Redondo Beach** | 356 | 7 | 1967 | 573.27 | 62.54 | 19.8 | 0.98 | 91.896 | 81.49 | 184.43 |
| **AES Redondo Beach** | 356 | 8 | 1967 | 573.27 | 62.54 | 19.8 | 0.98 | 91.771 | 81.49 | 184.43 |
| **Morro Bay Power Plant** | 259 | 3 | 1962 | 575.04 | 56.1 | 16.06 | 1.1 | 24.840 | 79.5 | 236.02 |
| **Morro Bay Power Plant** | 259 | 4 | 1963 | 575.04 | 56.1 | 16.06 | 1.1 | 24.824 | 79.5 | 236.02 |
| **Etiwanda Station** | 331 | 3 | 1963 | 575.05 | 68.11 | 14.03 | 0.98 | 19.808 | 97.27 | 150.14 |
| **Etiwanda Station** | 331 | 4 | 1963 | 575.05 | 68.11 | 14.03 | 0.98 | 19.808 | 97.27 | 150.14 |
| **AES Huntington Beach** | 335 | 1 | 1961 | 570.17 | 62.25 | 19.75 | 0.98 | 98.121 | 75.28 | 161.23 |
| **AES Huntington Beach** | 335 | 2 | 1958 | 570.17 | 62.25 | 19.75 | 0.98 | 98.152 | 75.28 | 161.23 |
| **AES Huntington Beach** | 335 | 3A | 1958 | 570.17 | 62.25 | 19.75 | 0.98 | 98.152 | 75.28 | 161.23 |
| **AES Huntington Beach** | 335 | 4A | 1961 | 570.17 | 62.25 | 19.75 | 0.98 | 98.350 | 75.28 | 161.23 |
| **Delta Energy Center, LLC** | 55333 | 1 | 2002 | 569.81 | 41.65 | 11.79 | 0.79 | 247.118 | 44.61 | |
| **Delta Energy Center, LLC** | 55333 | 2 | 2002 | 569.81 | 41.65 | 11.79 | 0.79 | 247.118 | 44.61 | |
| **Delta Energy Center, LLC** | 55333 | 3 | 2002 | 569.81 | 41.65 | 11.79 | 0.79 | 247.118 | 44.61 | |
| **Scattergood Station** | 404 | 1 | 1958 | 630.4 | 69.52 | 27.42 | 3.05 | 121.399 | 85.02 | 286.16 |
| **Scattergood Station** | 404 | 2 | 1959 | 630.4 | 69.52 | 27.42 | 3.05 | 121.399 | 85.02 | 286.16 |
| **Scattergood Station** | 404 | 3 | 1974 | 630.4 | 69.52 | 27.42 | 3.05 | 128.693 | 85.02 | 286.16 |
| **Coolwater Station** | 329 | 1 | 1961 | 575.06 | 69.92 | 18.14 | 0.98 | 2.514 | 103.78 | 279.05 |
| **Coolwater Station** | 329 | 2 | 1962 | 575.06 | 69.92 | 18.14 | 0.98 | 2.804 | 103.78 | 279.05 |
| **Coolwater Station** | 329 | 31 | 1978 | 574.74 | 60.92 | 13.5 | 0.83 | 31.403 | 67.55 | 279.05 |
| **Coolwater Station** | 329 | 32 | 1978 | 574.74 | 60.92 | 13.5 | 0.83 | 31.403 | 67.55 | 279.05 |
| **Coolwater Station** | 329 | 41 | 1978 | 574.74 | 60.92 | 13.5 | 0.83 | 31.403 | 67.55 | 279.05 |
| **Coolwater Station** | 329 | 42 | 1978 | 574.74 | 60.92 | 13.5 | 0.83 | 31.403 | 67.55 | 279.05 |
| **Cabrillo \| Encina Power** | 302 | 1 | 1954 | 571.36 | 63.03 | 18.07 | 1.06 | 198.838 | 70.57 | 329.91 |
| **Cabrillo \| Encina Power** | 302 | 2 | 1956 | 571.36 | 63.03 | 18.07 | 1.06 | 198.874 | 70.57 | 329.91 |
| **Cabrillo \| Encina Power** | 302 | 3 | 1958 | 571.36 | 63.03 | 18.07 | 1.06 | 198.929 | 70.57 | 329.91 |
| **Cabrillo \| Encina Power** | 302 | 4 | 1973 | 571.36 | 63.03 | 18.07 | 1.06 | 200.645 | 70.57 | 329.91 |
| **Cabrillo \| Encina Power** | 302 | 5 | 1978 | 571.36 | 63.03 | 18.07 | 1.06 | 200.916 | 70.57 | 329.91 |
| **Moss Landing** | 260 | 1A | 2002 | 568.99 | 39.23 | 10.1 | 0.78 | 217.023 | 42.7 | 223.04 |
| **Moss Landing** | 260 | 2A | 2002 | 568.99 | 39.23 | 10.1 | 0.78 | 217.023 | 42.7 | 223.04 |
| **Moss Landing** | 260 | 3A | 2002 | 568.99 | 39.23 | 10.1 | 0.78 | 217.023 | 42.7 | 223.04 |
| **Moss Landing** | 260 | 4A | 2002 | 568.99 | 39.23 | 10.1 | 0.78 | 217.023 | 42.7 | 223.04 |
| **Moss Landing** | 260 | 6-1 | 1967 | 572.92 | 49.08 | 17.76 | 1.09 | 71.433 | 60.35 | 223.04 |
| **Moss Landing** | 260 | 7-1 | 1968 | 572.92 | 49.08 | 17.76 | 1.09 | 71.450 | 60.35 | 223.04 |

`

### 3.2.1. Moss Landing Power Plant

*Industry Overview:* The Moss Landing electrical plant is the largest in California and is located in the Monterey Bay on the Central Coast. It has a combined output capacity of 2500 MW, enabling it to deliver a little over 4% of California's in state electrical generating capacity and about 7.4% of electric power CO2 emission[9].

*Production Statistics:* Its primary fuel like the majority of major plants in California is natural gas. It consumes an average just under 4 million mmBtu per month. While the fuel consumption has stayed relatively constant during off peak months over the last few years, recent updates have led to an increase in the plants baseload output. Whereas previous to 2005, a typical off-peak monthly output would be 250,000 MWh, new improvements have led to consistent base load output of 480,000 MWh per month[10] (output graph in Fig 2.6).

*Technology:* This difference highlights changes in the technology used at Moss Landing. In October of 2000 the California Energy commission approved the construction of new natural gas powered combined cycle units to replace the old Units 1-5 which had been in use since the plants initial construction in the 1950's and had been shut down in 1995. These new units came online in 2002, however the full effectiveness of these units did not come become apparent until 2005 where a large increase in the fuel efficiency of the plant from 30% to nearly 48% can clearly be seen. Where units 1-4 are new, units 6 and 7 are supercritical boilers that are less fuel efficient averaging at 35% efficiency. These units however are only used during the summer months and for a few hours a day in order to meet peak energy demand. Therefore, their effect on CO2 emissions of the peaking units is not very substantial. See Moss Landing efficiency graph in Figure 3.6.

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[9] Figures for 2005 provided by the California Energy Commission.
[10] Averages from 2003-2005 from EPA.

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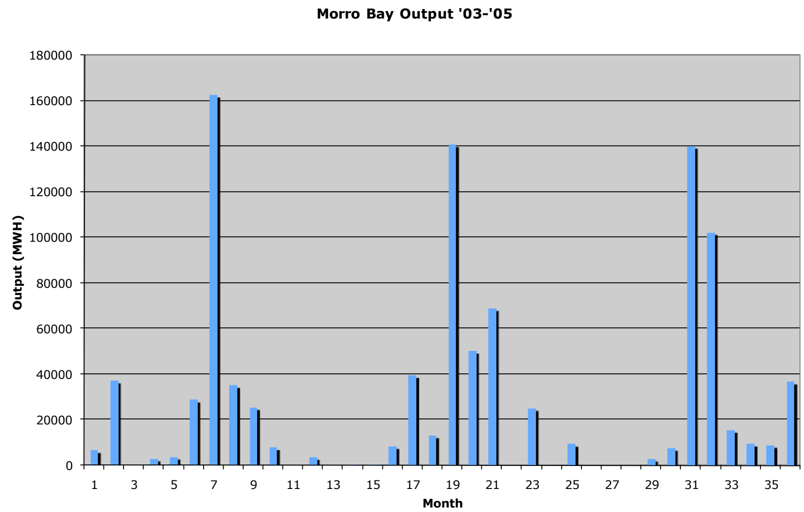
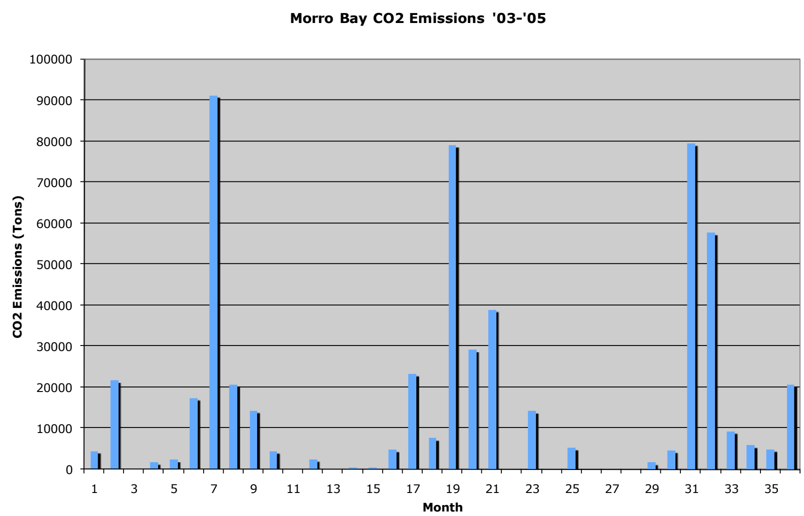
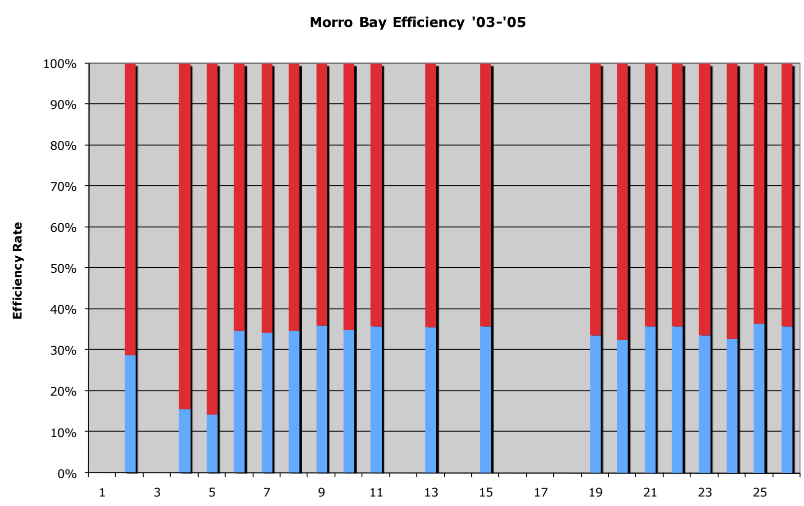
# Figure 3.6: Morro Bay



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*Emissions:* Regarding CO2 emissions, Moss Landing emitted a total of 2,376,736 tons of CO2 in 2005[11]. That figure is a decrease of 16.5% of emissions from 2004 when Moss Landing emitted 2,846,628 tons. This is despite an 8.4% increase in the MWh output from 2004 to 2005 of Moss Landing. One may reasonably expect that the actual effects of the new, more efficient technology coming on-line to be even greater in 2006 because Moss Landing was only operating at the more efficient levels of production for eight months of 2005. See Moss Landing CO2 Emissions graph in Figure 3.6.

*Costs and Competitiveness:* With regard to cost, it is difficult to interpret the exact dollar values of average and marginal costs. However, we have been able to break down the cost structure of firms based upon the vintage and efficiency of their capital. This is because the largest slice of marginal cost is taken up by fuel costs. Thus if we take the average price for one mmBtu of natural gas for 2004 ($5.81/mmBtu[12]) and convert that amount of energy to MWh with 30% efficiency versus 48% efficiency, we get a good estimation of the money saved on fuel per MWh. The result is that a plant with 48% efficiency will have a marginal fuel cost of $41/MWh while the less efficient plant will have a marginal fuel cost of $66/MWh. Thus, because of the upgrade, Moss Landing is now saving itself $25/MWh and reducing its marginal pollution (tCO2/MWh)

While fuel is the most consequential part of marginal cost, there are also variable operation and maintenance costs to consider. Like fuel cost per megawatt hour, these too vary based upon the vintage of the capital. Estimates however, show that these costs are initially quite low, averaging about $1/MWh to begin with and have a range of about $2/MWh.

Because of the upgrades this plant has undergone in the last few years. It ranks as number three in the competitiveness index indicated above. The following plant reviewed, Delta Energy Center, is ranked first in the competitiveness index and is a model of productivity maximization and externality minimization.

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[11] www.epa.gov

[12] www.energy.ca.gov/naturalgas/monthly_update/2004-08_NATURAL_GAS_UPDATE.PDF

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### 3.2.2. Delta Energy Center

*Delta Energy Center Industry Overview*: Delta Energy Center is a combined cycle natural gas plant (meaning it includes both gas and steam turbines) and upon construction was the largest power plant to come online in the state in 16 years[13]. It first came online in 2002 and has three units all located in Pittsburg with a generating capacity of 880 megawatts. The plant is big enough to serve every household in Contra Costa, Alameda and Solano counties and able to produce enough electricity to power about 660,000 homes or 1.3% of California Electric Generating capacity[14].

*Production Statistics:* As mentioned before Delta uses Natural Gas to generate electricity. Delta consumes 25,130,811 mmBtu a year and produces 5,740,290 MWh of electricity according to 2005 data. Of all the plants reviewed in this report Delta is the most efficient in terms of emission to output ratio and the most competitive (see competitiveness graph in figure 3). Figure 3.7 shows the output of Delta for the years 2003-2005, emissions, and efficiency. There is a noticeable increase in output and efficiency in the year 2005 which is most likely due to the plant being in full operation by that time. One may reasonably expect that the plant will continue operating at the 2005 levels of output in the foreseeable future given the relative currency of the technology.[15]

[13] The Chronicle Publishing Co. The San Francisco Chronicle June 18, 2002
[14] Ibid.
[15] http://cfpub.epa.gov/gdm/index.cfm?fuseaction=emissions.wizard

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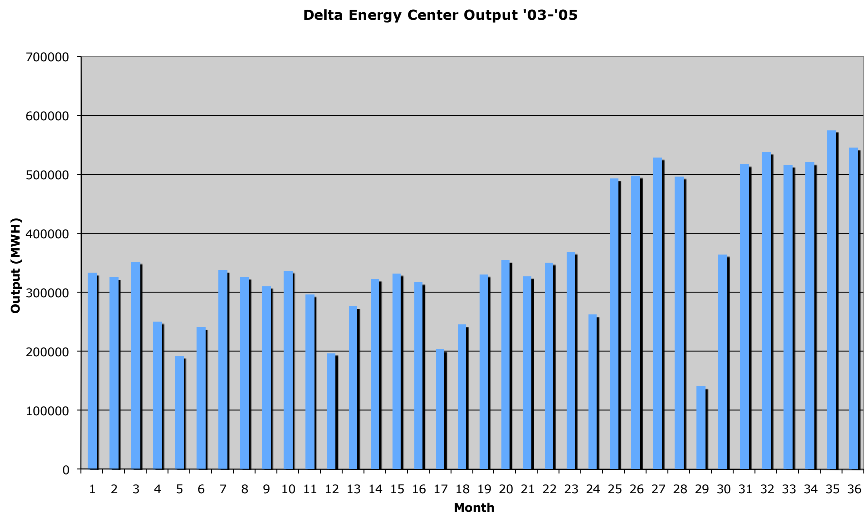
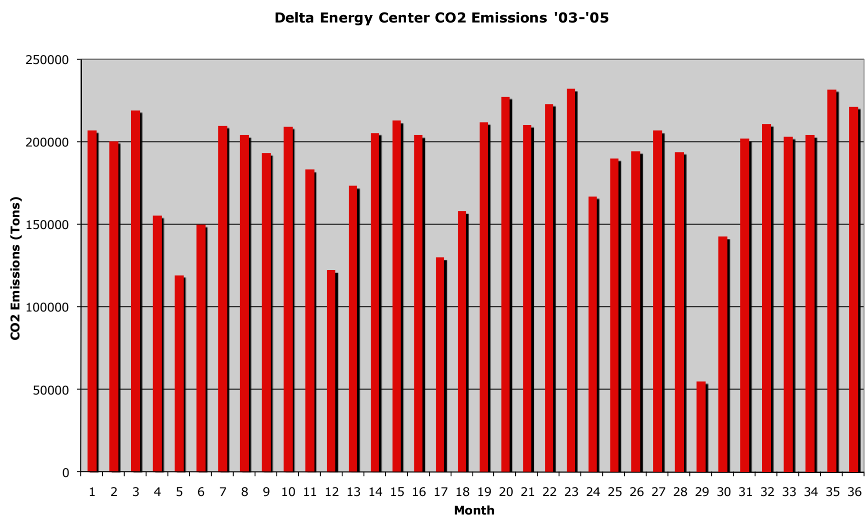
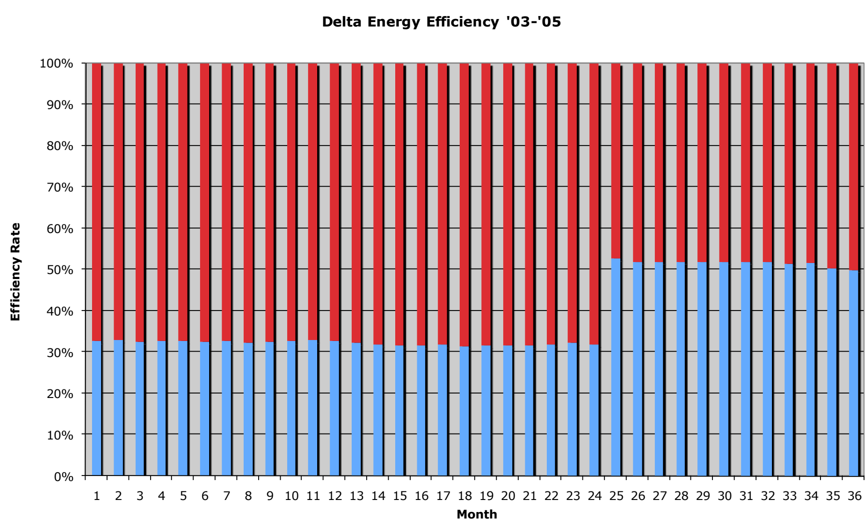
# Figure 3.7: Delta Energy Center



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*Technology:* The Delta plant uses combined cycle cogeneration technology in all three of its units in order to produce electricity[16]. This technology has proved to be the most efficient in electricity production with a 50% fuel efficiency output for all of 2005. This is the highest efficiency rate for all major plants in California. See Efficiency graph in Figure 3.7.

*CO2 Emissions:* The Delta energy center emitted 2,257,631.8 tons of CO2 in 2005 or approximately 7.1% of CO2 emissions by CA electrical plants[17]. Note that the CO2 emissions showed in Figure 3.7 do not mirror MWh output, as with most plants; despite consistent increases in Delta's productivity and output, CO2 emissions appear to be uniform over the 2003-2005 time period.

*Costs and Competitiveness:* Regarding costs, Delta's fuel efficiency allows it to minimize fuel costs by needing less fuel to reach its output goals. It's a model for other plants, as one can see in Fig 2.3 it has the lowest marginal cost of production at every price of fuel. Again this marginal cost is excluding non-fuel variable operation and maintenance costs because of the scarcity of such data, nonetheless as described above, these costs are far too small per MWh to make up the differences in fuel costs except when fuel is at unrealistically low prices. As a result of its high efficiency and low emission rates, Delta Energy center ranks the highest on the competitiveness index among the critical electrical power plants.

[16] www.energy.ca.gov/sitingcases/delta/description.html
[17] http://cfpub.epa.gov/gdm/index.cfm?fuseaction=emissions.wizard

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### 3.2.3. AES Alamitos Generating Station

*Industry Overview:* AES, Alamitos Generating Station is a private electricity generating company operating under contract with Southland in Southern California. AES Alamitos first began operating in 1956[18]. The plant is located in Long Beach California and has six power generating units all located in close proximity to one another near the Los Cerittos Channel. The company has had a turbulent financial year due to environmental law suits and aging facilities and had to shut down some of its units in 2005 for repair and environmental upgrades, for this reason we shall be using 2004 data for this report. None the less AES is the third greatest electricity provider in Southern California. When the plant is operating at full output it is accountable for 3.3% of California's electrical capacity. See table 1 for plant rank in MW capacity.

*Production Statistics:* AES Alamitos uses Natural Gas and Distillate Oil to produce electricity[19]. The plant uses 35,052,895 mmBtu to produce 3,019,127 MWh per year according to 2004 data. In comparison to the other plants in this report Alamitos is the least efficient energy producer of all the plants this report reviewed, producing the least electricity per mmBtu of input. Output, emissions, and efficiency are presented in Figure 3.8.

[18] www.aes.com
[19] Ibid.

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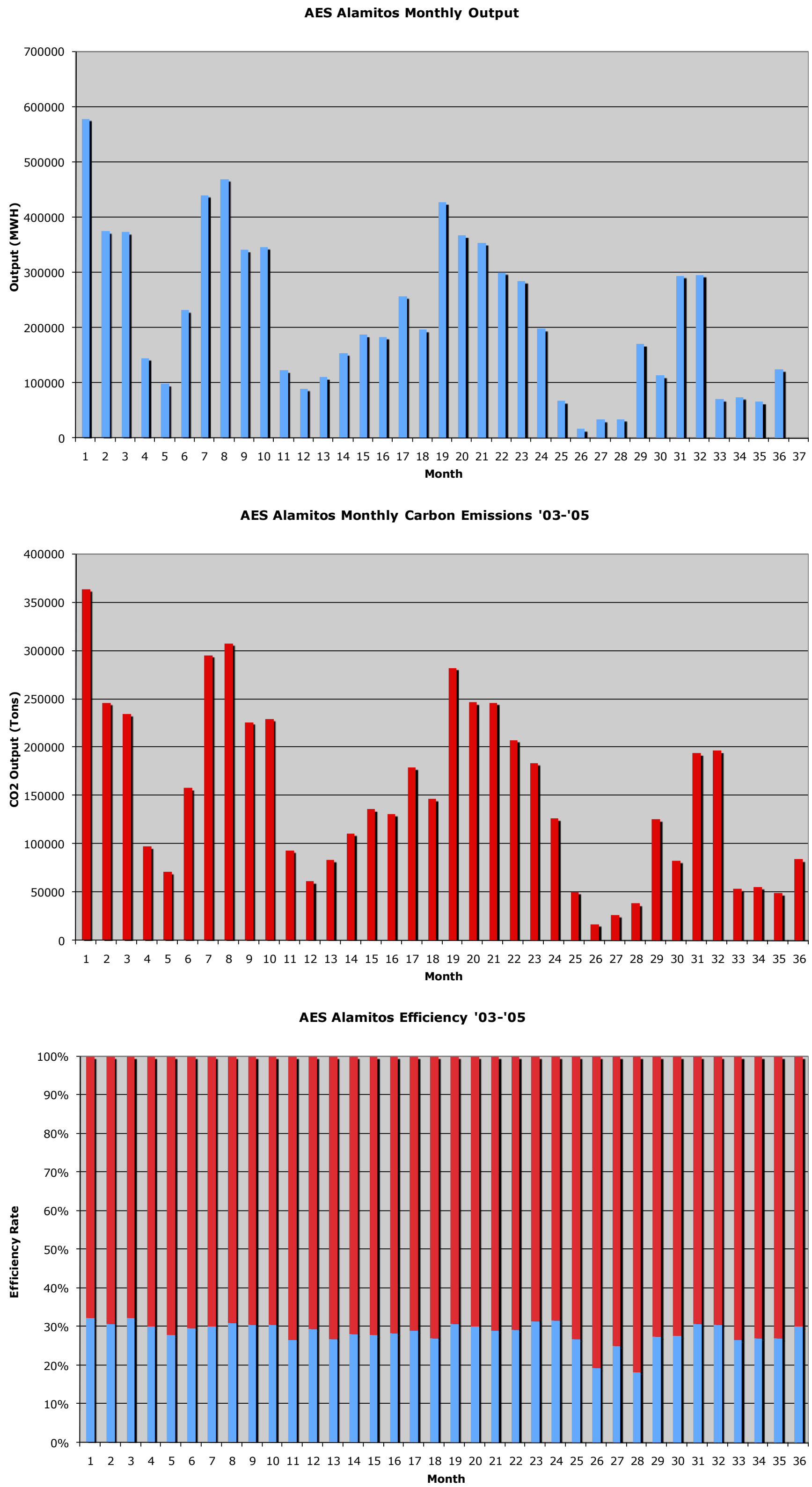
## Figure 3.8: AES Alamitos



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*Technology:* The low mmBtu to output ratio is primarily due to depreciation of infrastructure. The Alamitos units use conventional GE/Westinghouse steam turbines, Babcock and Wilcox Combustion Engineering boilers and Pratt & Whitney aircraft turbines[20] to generate electricity. The six generating units of Alamitos came online successively from 1956 through 1966. As a result their production is polluting, and costly (see figures 6 and 8 for output and plant efficiency) As a result of the lawsuits in 2005, efficiency information for that year may be inaccurate, however, their fuel efficiency average over three years comes out to 28.5% which puts them at the lowest average fuel efficiency for all plants in this report.

*CO2 Emissions:* AES produced 2,082,825.2 tons of CO2 in 2004 when all its units were in operation. In 2005 the CO2 emissions dipped to 974,950.4 and in 2006 with the increase in electricity output CO2 emissions rose to 1,406,909[21]. Though the company website says that it is in support of the California CO2 emission reduction they have yet to act upon their word and make changes towards lowering CO2 emissions at the AES Alamitos plant. Their emission to output (tCO2/MWh) ratios for these periods were: 0.786 in 2005 and 0.698 in 2004.

*Costs and Competitiveness:* AES Alamitos has been involved in various lawsuits concerning the environment. A record $17 million fine for excessive nitrogen oxide (NOx) emissions was imposed on Alamitos by the South Coast Air Quality Management (SCAQM) in 2000, in addition to the fine the company had to pay for the installation of expensive NOx reducing equipment[22]. The generating station was also fined for dumping hot water into the Los Cerittos river and disturbing aquatic life. Aside from legal costs, the Alamitos generating plant is highly vulnerable to price spikes in Natural gas. With such a low fuel efficiency capacity Alamitos emits far more CO2 and generates far less output than modern technology would allow. The AES Alamitos website claims that they are upgrading their capital though there are not any other reports to substantiate this claim. As a result of the high emission to output rate and

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[20] Ibid.
[21] http://cfpub.epa.gov/gdm/index.cfm?fuseaction=emissions.wizard
[22] http://www.environmental-finance.com/2000/newsdec2.htm

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low efficiency, Alamitos ranks as the least competitive major natural gas plants in the state in the competitiveness index introduced earlier (Figure 3.5).

### *3.2.4. Haynes Generating Station*

*Haynes Industry Overview:* Haynes generating station is located in Long Beach and first came on line in 1962. It has 6 Units with a capacity of 1570 MW, supplying 2.5% of total California electricity capacity[23].

*Production Statistics:* Haynes's primary fuel is natural gas, of which it consumes 31,555,920 mmBtu to produce 3,786,978MWh in 2005. Also in that year, it installed new equipment which increase overall fuel efficiency, the new units came on line in 2005 and one can see the rise in productivity for all months in 2005 versus in the years 2004 and 2003 in the Figure 3.9 measuring monthly output, emissions, and efficiency, also take note of the efficiency rise. One can expect an even greater increase in fuel to output efficiency when as two additional units are expected to go online in 2008.

*Technology:* The Los Angeles Department of Water and Power (LADWP) invested in the modernization of two units at Haynes Generating Station. The new installations feature combined cycle units with cogeneration capacities. As a result, these new units have a much higher fuel efficiency rate (48%) then the older units of the plant that are still in operation which averaged about 30% efficiency in 2005, see efficiency graph in Figure 3.9. These numbers place the plant in a similar position as Moss Landing except for that Moss Landing modernized all of its base-load units whereas Haynes is still highly dependent on old technology, as a result the average fuel efficiency remains 40.6%. This may be changing however as LADWP also plans to renovate generators 5&6 by 2008[24] and has increased investment in developing renewable energy resources.

[23] www.powermag.com/topplants/2005/Gas%20Oil_Avg%20heat%20rate.pdf?S=n
[24] Business Wire, April 15th, 2005.
http://www.findarticles.com/p/articles/mi_m0EIN/is_2005_April_14/ai_n13608801

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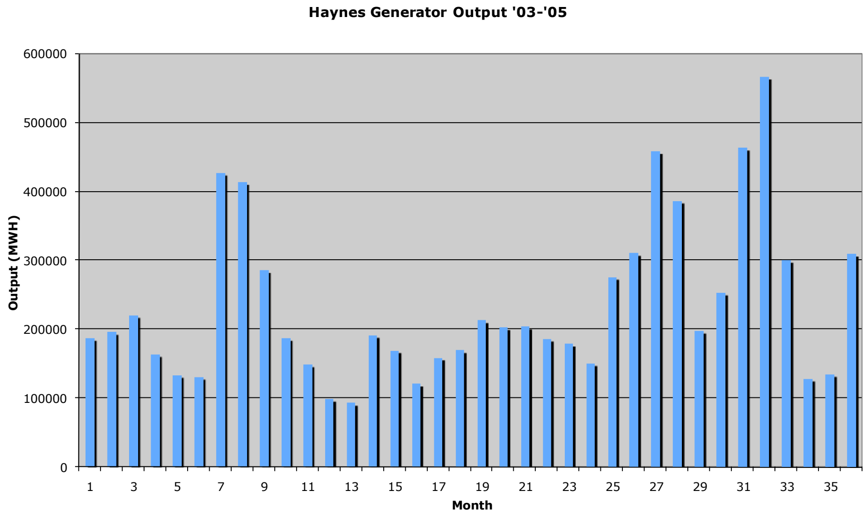
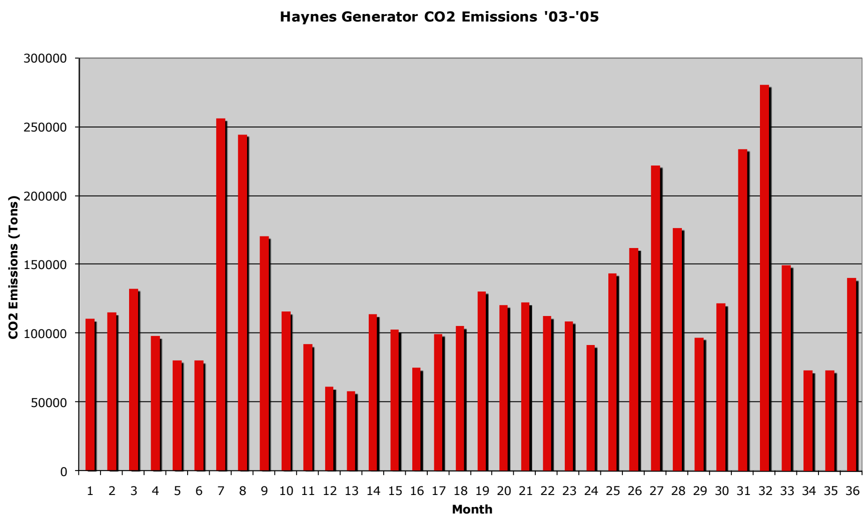
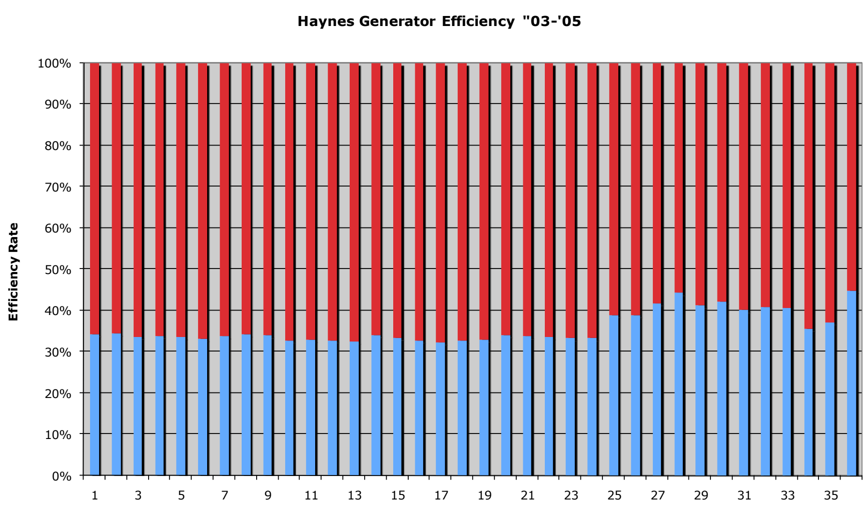
# Figure 3.9: Haynes Generator



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*CO2 Emissions:* Haynes emitted a total of 1,875,176.8 tons of CO2 in 2005,[25] which is about 5.9% of emissions by California electrical plants. The emissions graph in Figure 14 shows an increase in CO2 emissions in 2005, however this is just a reflection of higher MWh output. The efficiency of the plant has indeed gone up with the update of the two units and the ratio of total CO2 per MWh going down in 2005 from a 2003 yearly average of 0.6 to the 2005 average of 0.5. One can expect that the CO2 to MWh ratio will continue to go down with the addition of new technology in 2008.

*Costs and Competitiveness:* The costs involved in operating the newer units are far less than the older once again mostly because of savings from fuel efficiency. In this case however, it is not only due to fuel efficiency. The fuel required to power the new cogeneration turbines is actually cheaper at about 510 cents/mmBtu whereas the older turbines use a fuel 641.93cents/mmBtu to produce much less output. This results in a a marginal difference of almost 30 $/MWh that is saved by using the newer technology. Again, differences in operation and maintenance cost are present but difficult to get an exact measure on and relatively small compared to differences in marginal cost that result from differing fuel efficiencies.

### *3.2.5. Coal Plants: Mohave(NV) and Intermountain(UT)*

*Industry Overview:* There are fewer coal-fired plants in California compared to the rest of the nation. Of the two major coal plants in the top 20 of generating capacity, both are out of state and one, Mohave Power Plant located in Nevada was shut down at the end of 2005. However, the data of both plants will be provided as examples of a "typical" coal plant. Mohave was owned partially by SCE before the shutdown and Intermountain, located in Utah is owned predominantly by the Intermountain Power

[25] www.epa.gov

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Agency which is not located in California. However, the LADWP is a partial stakeholder.

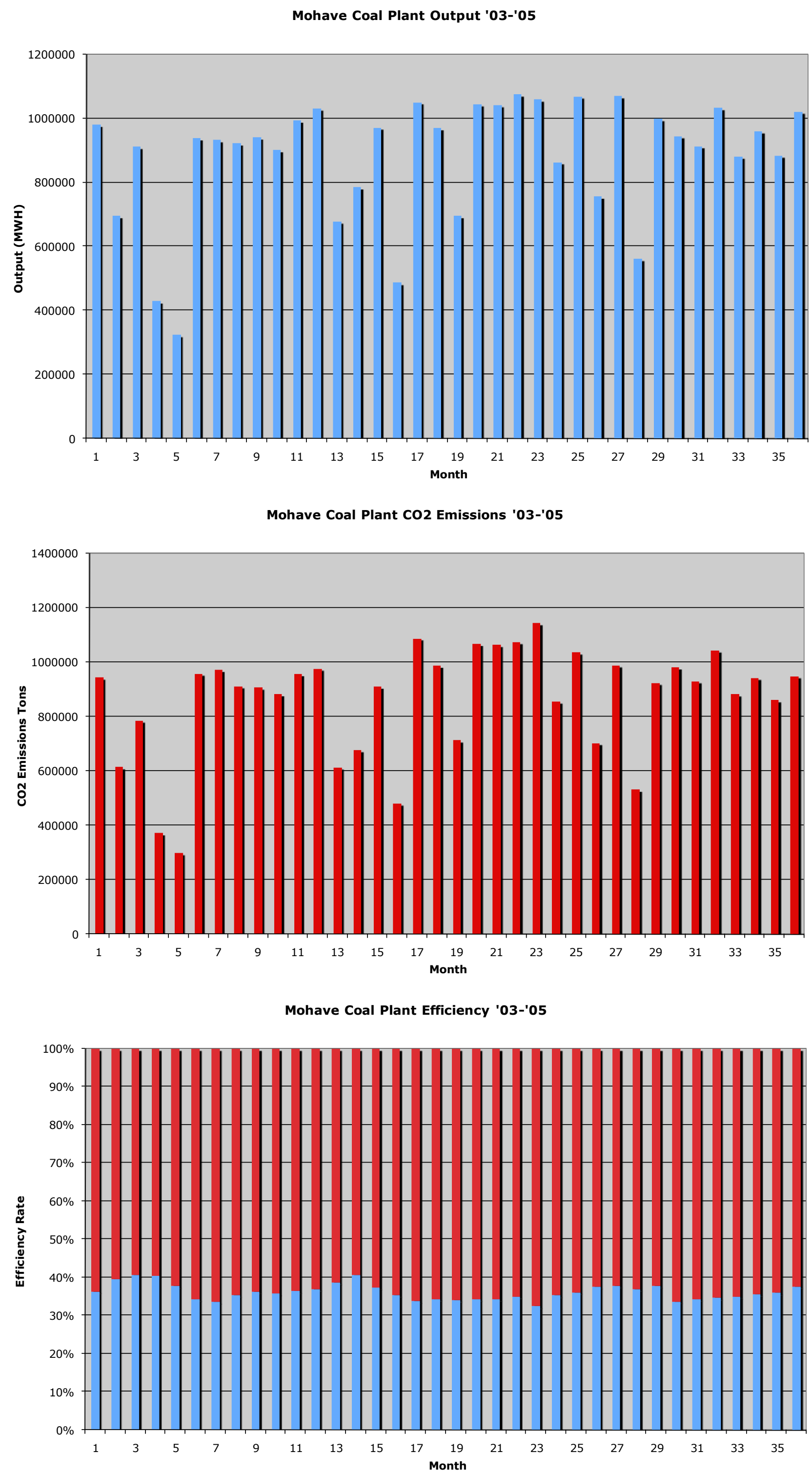
*Production Statistics:* It is difficult to discern exactly how much of these plants' output is imported to California. However, coal powered generation makes a total of 9.8% of California's electricity. The two plants are nearly identical as their On-line MW capacity is 1640 MW for Intermountain and 1636 for Mohave. In 2005, it's last year of operation, Mohave Generating Station produced 11,093,073 MWh. At a similar level Intermountain produced 14,564,401 MWh.

The reason that Mohave and Intermountain produce a greater annual output than Moss Landing, California's largest plant, despite a lower MW capacity is that Mohave and Intermountain don't seem to exhibit a peaking cycle as do most of the gas-powered plants in California. If one looks at the output graphs, they produce at a relatively constant level throughout the year.

*Technology:* The technology used at Mohave was tangentially-fired processes with an electrostatic precipitator to control emissions. At Intermountain the type of unit is a dry-bottom, wall-fired boiler with a "baghouse" method of reducing emissions. The result was an average monthly efficiency of 36.9% over the last three years for Mohave and 33.6% for Intermountain. These efficiency rates are not as good as the newer and modernized natural gas plants such as Moss Landing and Delta, however it is more efficient than many of the gas plants.

*Emissions:* Mohave's total $CO_2$ emissions for 2005 were The emission to output ratio for Mohave was 0.971 $tCO_2$/MWh while Intermountain was a slightly larger emitter at 1.042. These are the highest ratios of any of the plants profiled in this report. However, that level is average for the type of fuel being used.

## Figure 3.10: Mohave Coal Plant




*Costs and Competitiveness:* At the April through June 2006 average price of \$51.72/ton and the average yield of 12000 Btu/pound of central Appalachian coal, the

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average fuel price of production is $2.15/mmBtu. The marginal cost of fuel at the respective efficiencies of the plants is approximately $20/MWh. This is a much lower marginal cost of fuel than the natural gas fired plants. As a result, they are likely to remain competitive even with a tax on emissions which are an order of magnitude higher than the natural gas plants. Despite the low marginal cost of fuel, a strong cap on their emissions could push costs up enough to render these plants less competitive. As a result, they have the lowest rank of all plants on the competitiveness index.

### *3.2.6. Structural Transition in the Electric Power Industry*

It is clear that the key to competitiveness in the future will be fuel efficiency and this factor will only become more decisive as GHG regulation becomes more stringent. In an environment of rising fuel costs, differences in this efficiency become burdensome for those who are realizing only 30% of the energy potential of their fuels. In a significant way, efficiency will intensify economic disparities between plants with different vintages of technology. This is good news for recent investors because it accelerates pay offs and rewards new adoption. Nonetheless, new investments will certainly be needed, and more so the more determined the regime of climate action policies. Only seven of the top 20 plants providing energy to California have come online since 1970 and two of those are the coal plants described above. Thus the top tier of energy providers to California is dominated by 35+ year old technology. As Moss Landing exemplifies, a technological upgrade can induce a 16.5% drop in absolute emission levels, accompanied by an 8% rise in absolute output. Thus if California wishes to achieve the emission goals set by AB32, the most likely path will not be major cutbacks in production but aggressive innovation and technology adoption.

Because the working life of these capital goods spans several decades, these adjustments will establish new baselines for emission intensity and accelerate the need for future efficiency improvements.

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# 4. CEMENT PRODUCTION IN CALIFORNIA

The cement industry is quite literally fundamental to California's infrastructure and the myriad of services provided by it, including transport facilities and commercial and residential infrastructure architecture. As such, it is one of the state's most important strategic sectors. The California cement industry employed around 2,000 workers in 2002 and $1 billion in direct revenue. Indirect employment, including concrete and ready-mix manufacture and distribution, is estimated at 19,000, with revenues approaching $4.1 billion (CEC:2005).

Cement production also makes significant contributions to GHG emissions in California, representing about 2.4% of statewide CO2 but less than 0.1% of GSP. Thus Cement is likely to be considered a first-tier emitter in the context of a prospective state carbon cap. This sector represents less than .Having said this, the sector has a variety of important and incentive compatible market options for GHG mitigation, including increased use of limestone Portland cement and (fly ash) blended cement, which have an estimated potential to contribute 70% of to a cumulative (over 2005-2025) reduction of 38 MMTCO2 reduction from all measures examined costing less than $10 per metric ton carbon equivalent (MTCE) (CCAP:2005). The use of waste tires as fuel would permit an estimated additional emission reduction of 10% (Ibid.).

## 4.1. Modelling Approach

In contrast to the electric power sector, we consider only one tier of industrial structure, a set of twelve individual producers each with its own technology and cost structure. Schematically, the market structure of this sector is described in Figure 3.1 below. Within the sector, each cement producer is represented by an individual plant that hires factors of production (labor, capital, energy) according to CES value added aggregations and uses intermediate inputs in Leontief constant (Input-Output) proportions to individual plant output (schematic Figure 3.2).

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As we discuss later in this section intensive efforts were made to identify production calibration data at the plant level. Unfortunately, these were only partially successful, limiting the degree to which real or potential plant heterogeneity will influence structural adjustment in this sector. Improved data sources could sharpen the model's ability to capture competitive differences and simulate their implications for sectoral adjustment patterns, but the data we have already obtained actually suggest that practical differences within the sector are limited. Cost structures are broadly comparable, with similar incidence of fuel, raw material, and transport expenses. The primary remaining difference at the plant level is vintage of capital equipment.

**Figure 3.1: Schematic Structure of the Cement Sector**

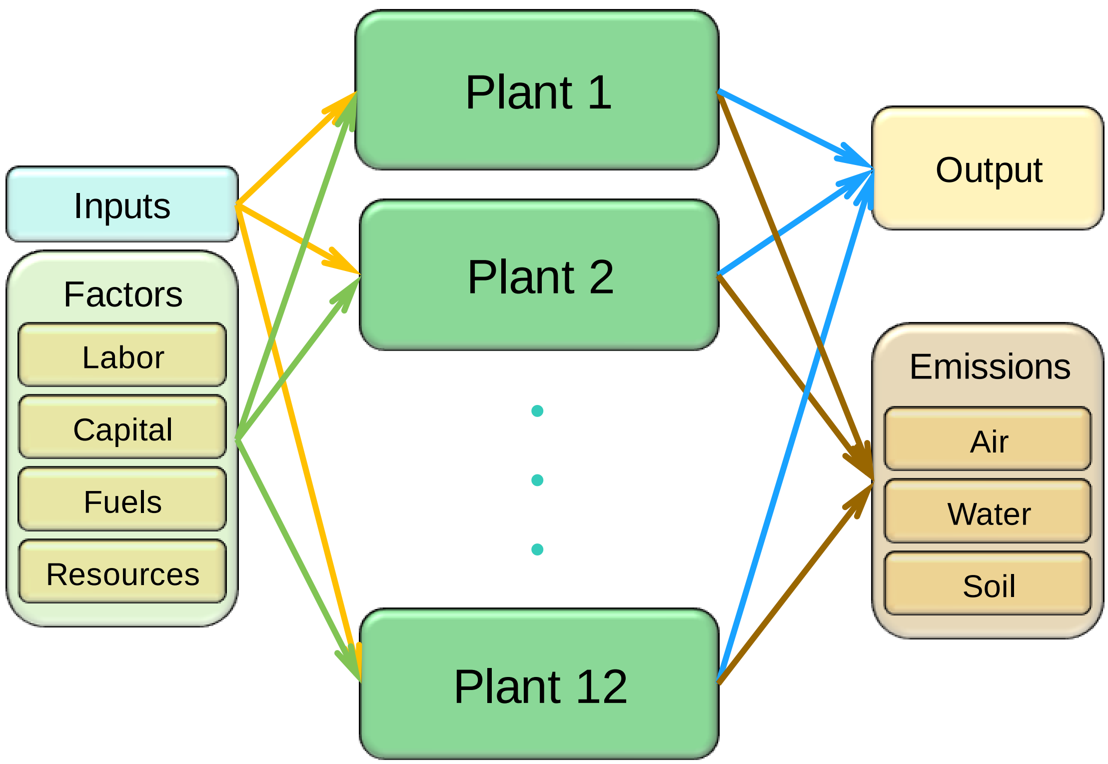

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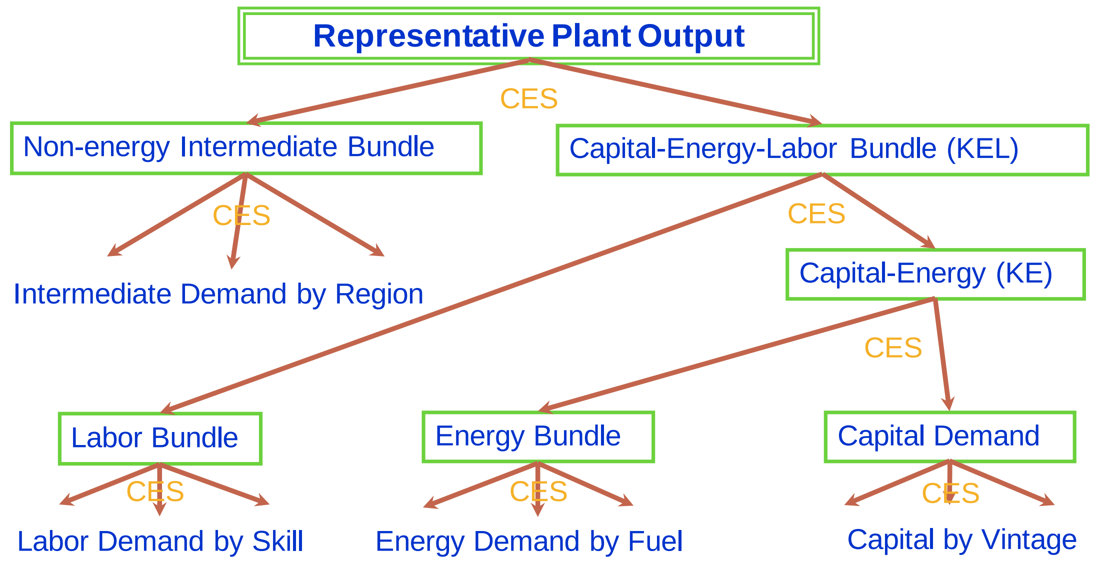
**Figure 3.2: Schematic Input and Factor Use for a Representative Cement Plant**




### *4.1.1. Data Sources*

In order to simulate this sector's response to state GHG mitigation measures, we begin with the Climate Action policy package proposed by CalEPA in January, 2006. The effects of this were estimated using industry Marginal Abatement Curves (MACs) devised by the Center for Clean Air Policy (CCAP:2005). At that time, a total of fourteen measures used by CCAP to construct their MAC curves were examined:

1. Limestone Blended Cement
2. Preventative Maintenance
3. Process Control & Management
4. Waste Tire Fuel
5. Clinker Cooler Control
6. On-line Kiln Feed Analyzer
7. Kiln Shell Heat Loss Reduction
8. Optimized Heat Recovery in Clinker Cooler
9. Precalciner on Dry Preheater Kiln
10. Planetary to Grate Cooler
11. Seal Maintenance
12. Blended Cements
13. Long Dry to Preheater, Precalciner Kilns
14. CemStar without License after 2014

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The primary data source is a report by the Center for Clean Air Policy (CCAP:2005a) and the spreadsheets that were used for their analysis (CCAP: 2005b), detailing Marginal Abatement Cost (MAC) estimates for over thirty measures in the cement sector. Costs were expressed in 2003 dollars, so no adjustment for BEAR was necessary. CCAP constructed three different MAC curves using discount rates of 4%, 7%, and 20%. To maintain consistency with the other types of measures used in BEAR, the 4% rate scenario was used as the basis for our analysis. An additional manipulation of the data was also necessary. The stream of GHG savings was discounted for purposes of recalculating the annualized abatement costs. Since only three of the fourteen measures exhibit positive costs at the 4% discount rate, this does not have much impact on the adoption of these measures by BEAR. Expenditures for equipment are mapped from the cement industry to the construction industry. Increased costs for improved maintenance procedures remain within the cement industry. This simulation was reported separately in more detail in Roland-Holst:2006.

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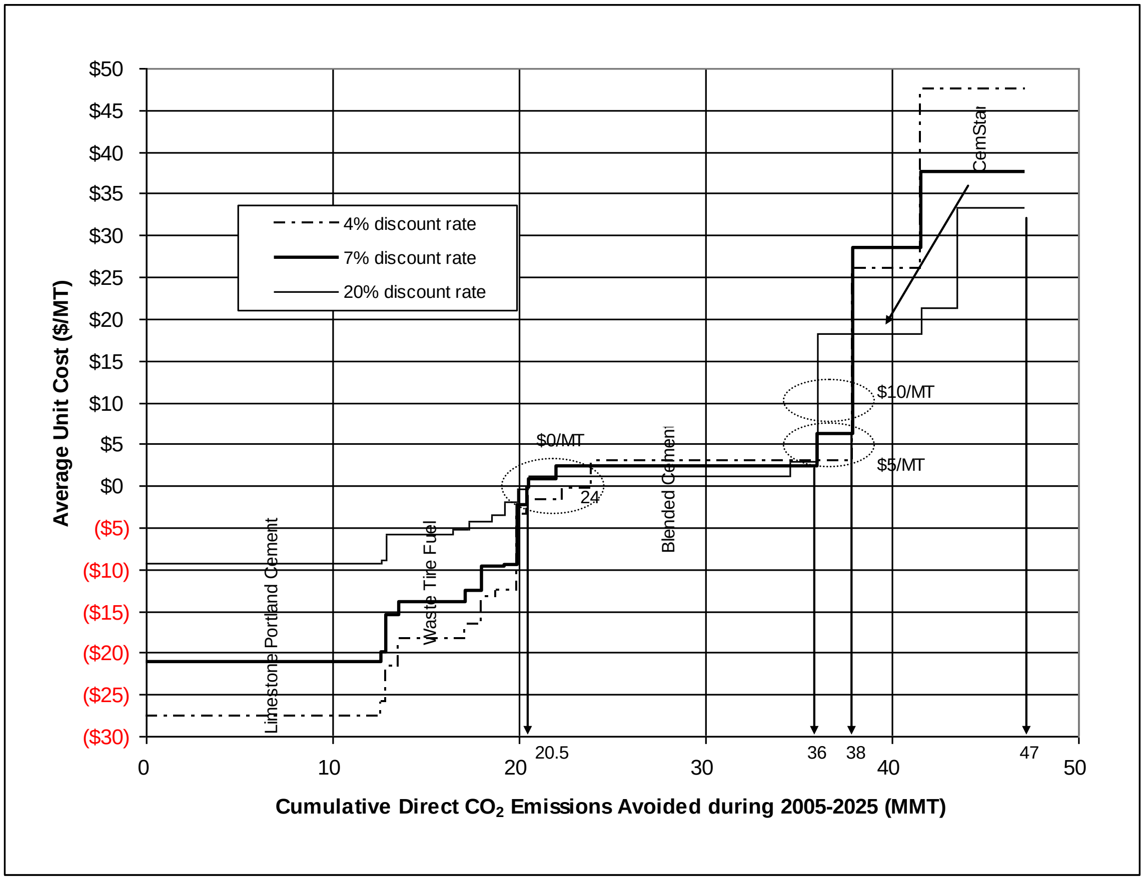
**Figure 3.3: Marginal Abatement Curve Estimates for Cement**




Source: CCAP:2005

## 4.2. Overview of Industrial Structure

The state is currently relatively self-sufficient in cement, with production trending close to demand in the 10-15 MMT over the last five years. At the same time, the sector accounts for about 12 MMT of CO2 emissions, 88% of which arise directly from producing cement (concrete accounts for 11%) (CEC:2005).There are eleven major cement producing plants in the state and one grinding plant (Portland…A, 2004). These are distributed throughout the state, with one in Northern California, two in proximity to the Bay Area, and the rest distributed throughout Southern California (Figure 3.4). The state is responsible for 8-10 percent of national cement demand, and prices are generally above national averages (particularly in Northern California, see Table 3.1).

**Figure 3.4: California Cement Production Facilities and Levels**

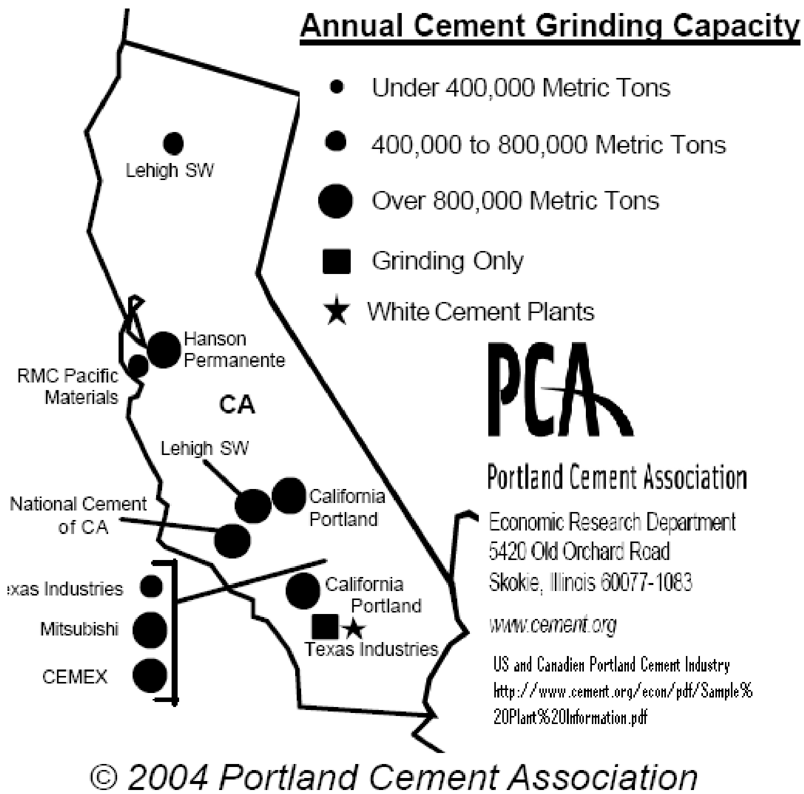



**Table 3.1: California Output and Price Indicators**

| | | Quantity (MT) | Percent | Price ($/MT) | Ratio |
|---|---|---|---|---|---|
| **2003** | **N. California** | 3,751 | 2.34 | 80.69 | 110 |
| | **S. California** | 9,881 | 6.18 | 74.97 | 102 |
| | **U.S.** | 160,000 | 100.00 | 73.50 | 100 |
| **2004** | **N. California** | 4,257 | 3.70 | 86.88 | 111 |
| | **S. California** | 10,764 | 9.36 | 81.87 | 105 |
| | **U.S.** | 115,000 | 100.00 | 78.00 | 100 |

Source: Van Oss: 2004.

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## 4.3. Cost determinants for cement producers in California

As with other economic activities that represent direct GHG emission sources, energy costs will be a primary determinant of the cement industry's response to policies that restrict CO2 emissions. Because of its heat-intensive production technology, cement relies heavily on energy inputs, and together with raw materials these dominate variable costs in an industry where variable costs are more than half all operating expenses. Among energy costs, electricity represents over 10% of overall production cost, while natural gas can make up 1-5%, depending on choice of technology and alternative fuel (coal, tires, etc.). Labor is not a significant portion of production costs (Coito, et al, 2005 provides details on all these components.). A table from the 2002 census estimating total cost and value of California cement shipments, and other industry statistics (Annex Table 3.1).

Of special significance to the present discussion is transportation cost. The distribution of California cement plants depends on two primary factors: location of limestone (the principal raw material input) and market location. The latter is an essential consideration because of the low value/density ratio for this product. "Cement plants have substantial incentives to locate near the largest markets they serve" (Hanle, 2004). The *Regulatory Impact Report* comments on this feature of the industry: "The U.S. Portland cement industry is fragmented into regional markets rather than a single national market. Because of its low value-to-weight ratio, the relative cost of transporting cement is high and limits the geographic area in which each producer can supply its product economically. Since Portland cement is a homogeneous product, buyers are unable to distinguish between the product of sellers in the market so that the geographic bounds of each market are solely determined by the costs of transport. Generally, cement sales are made within a radius of 200 to 300 miles of each plant, with access to river transport allowing manufacturers or producers to expand beyond that radius. About 89% of US cement is shipped by truck (Regulatory…Rulemaking, 1998). " Hendrik Van Oss estimates freight costs to range from $10-30 per ton. These

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are sometimes borne by concrete manufacturers, who pick up the cement directly from the plants (Personal…Van Oss, 2006).

Because of its geographic extent, California mirrors this national framework, with markets segmented into Northern and Southern regions (see again Figure 3.3). The Bay Area and Sacramento region are separated from the Los Angeles basin and San Diegoby more than the maximum efficient radius, and maritime transport is not generally considered an attractive option for bridging these markets. This may in part explain the persistent price differences between the two markets (Table 3.1). Finally, California is relatively isolated from other metropolitan markets, the nearest being Portland and Phoenix, both more than 500 miles from the nearest of the two California markets. These considerations exert important limitations on the industry's ability to re-locate in response to changing market and regulatory conditions.

From the industry perspective, Chairman of PCA and CEO of California Portland James Repman commented in an interview that chronic cement shortages and an inability to satisfy consumer demand in the short term.[source] Levels of demand have exceeded all expectations and forecasts, and ability to import has been seriously constrained by freight and shipping costs. Repman notes further limitations to shipping, such as the unreliability and limited availability of rail systems (something that will not change without substantial investments in infrastructure), and the prohibitive costs of trucking. (Cement Americas, 2004) The California cement market has seen a downturn recently, and growth is expected to slow (Tables A3.6 and A3.7 provide more detail on this).

## 4.4. General Emissions and Energy Use

An extensive review of the literature on California's cement production has revealed a number of salient characteristics. Overall, the cement manufacturing process uses energy at four stages: raw material preparation, clinker production, and finish grinding. The first of these steps is the most electricity-intensive, requiring generally about 23-32 kWh/short ton, although it could require as little as 10 kWh/short ton (Coito, et al, 2005) (see also Figure 3.5) The kiln process produces so called clinker,

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the solid feed stock for grinders that produce finished cement. Portland cement clinker is made by heating, in a kiln, an homogenous mixture of raw materials to a sintering temperature, which is about 1450°C for modern cements (Taylor: 1990). Clinker production is the most energy-intensive stage in cement production, accounting for over 90% of total industry energy use, and virtually all of the fuel use (Coito, et al, 2005). Due to the very high temperatures reached in cement kilns, a large variety of fuel sources can be used to provide energy. Coal is responsible for the largest share of energy consumption at cement kilns, approximately 71% in 2001. Approximately 12% of energy consumption is derived from petroleum coke, 9% from liquid and solid waste fuels, 4% from natural gas, and the remainder from oil and coke (Hanle, 2004).

Dry kilns require more electricity to operate due to the need for fans and blowers; however, they consume significantly less energy fuels for heating. On average, the wet process has been estimated to require 6.3 Million Btu per short ton (MBtu/st) versus 5.5 MBtu/st for the dry process (Hanle, 2004).

CO2 is emitted in three stages of cement production (1) fuel combustion, typically coal, in cement kilns, (2) offsite and onsite power generation, and (3) in the clinker-making process. Total emissions, including from transportation are estimated to be 10.4 Mt CO2 (2.8 MtC). […] In the United States Average emission intensity for cement making is estimated to be 1047 kgCO2e/t cement, which includes mining and transport of raw materials (PIER: 2005). (see table 2). Emissions from clinker production account for nearly half of CO2 produced (Van Oss, personal communication).

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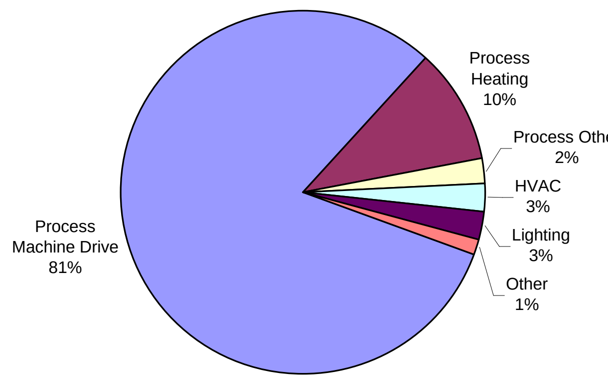
**Figure 3.5: Cement Industry End Use Electricity Consumption**




Source: 1998 MECS **(**Manufacturing Energy Consumption Survey **)**

On a national basis, the cement industry is becoming increasingly concentrated, with a few multinational cement companies assuming ownership of increasing shares of cement manufacturing capacity. A similar trend is apparent in $CO_2$ emissions, where it has been estimated that five companies were responsible for roughly 50% of $CO_2$ emissions from the U.S. cement industry, and the top ten accounted for nearly 70% of emissions (Hanle, 2004).

The California cement industry is a major energy consumer, with annual (2002) demand for 1,600 GWh of electricity, 22 million therms of natural gas, 2.3 million tons of coal, and smaller amounts of coke and waste materials including tires. This represents about 5% of electricity consumption and 1% of natural gas consumption for all of California industry (Coito, et al, 2005). (See Table 4 for *General Plant Energy Usage* Energy Institute Estimates).

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## 4.5. General Emissions Reduction Opportunities

Because of the dominant cost represented by kiln fuel consumption, energy efficiency must be recognized as a primary means of improving both production efficiency and GHG mitigation in the cement sector. The main energy-efficiency opportunities in the kiln are conversion to more advanced technologies (i.e., pre-calciner multi-stage pre-heater kiln), optimization of clinker cooling, improvement of preheating efficiency, improved burners, and process control and management systems. Electricity use can be reduced through improved grinding systems, high-efficiency classifiers, high-efficiency motor systems, and process control systems. Table 3.2 provides a list of energy-efficient practices and technologies for cement production, including (but not limited to) those set forth by the CalEPA Climate Action Team (Coito, et al, 2005; Worrell and Galitsky, 2004).

In personal communication, Handrik Van Oss noted that the opportunities for reducing emissions from burning limestone (clinker production), a source representing nearly half of cement CO2 emissions, are limited. CO2 fumes from kilns are 'diffuse', i.e. bundled with a host of other emissions, making filtration very expensive. He believes more cost effective improvements would either have to come from alternative fuels or blended cements. He further noted that, if the industries producing fly ash or slag are regulated, the costs of these might increase dramatically, leaving the cement industry with fewer options for cost effective emission reduction. It can also be noted that waste derived fuels, such as from tires, also could contribute significantly to emission reductions.

The blended cement issue is further complicated by an impasse with the industry's largest customer, a public transportation agency. CalTrans has not yet determined that blended cement meets is general design specifications for transport infrastructure. An adverse decision in this context would seriously limit the profitability of investments in blending technology, reduce the scope of emission/efficient cement sales, and deny the industry a very important market and engineering standards precedent.

**Table 3.2: Energy Savings Opportunities in Cement Production**

<table>
<tr><td colspan="2">Raw Materials Preparation<br>Efficient transport systems (dry process)<br>Slurry blending and homogenization (wet process)<br>Raw meal blending systems (dry process)<br>Conversion to closed circuit wash mill (wet process)<br>High-efficiency roller mills (dry cement)<br>High-efficiency classifiers (dry cement)<br>Fuel preparation: Roller mills</td></tr>
<tr><td>Clinker Production (Wet)<br>Energy management and process control<br>Seal replacement<br>Kiln combustion system improvements<br>Kiln shell heat loss reduction<br>Use of waste fuels<br>Conversion to modern grate cooler<br>Refractories<br>Optimize grate coolers<br>Conversion to pre-heater, pre-calciner kilns<br>Conversion to semi-dry kiln (slurry drier)<br>Conversion to semi-wet kiln<br>Efficient kiln drives<br>Oxygen enrichment</td><td>Clinker Production (Dry)<br>Energy management and process control<br>Seal replacement<br>Kiln combustion system improvements<br>Kiln shell heat loss reduction<br>Use of waste fuels<br>Conversion to modern grate cooler<br>Refractories<br>Heat recovery for power generation<br>Low pressure drop cyclones<br>Optimize grate coolers<br>Addition of pre-calciner to pre-heater kiln<br>Conversion to multi-stage pre-heater kiln<br>Efficient kiln drives<br>Oxygen enrichment</td></tr>
<tr><td colspan="2">Finish Grinding<br>Energy management and process control<br>Improved grinding media (ball mills)<br>High-pressure roller press<br>High efficiency classifiers</td></tr>
<tr><td colspan="2">General Measures<br>Preventative maintenance (insulation, compressed air system, maintenance)<br>High efficiency motors<br>Efficient fans with variable speed drives<br>Optimization of compressed air systems<br>Efficient lighting</td></tr>
</table>

Source: Worrell and Galitsky (2004)

## 4.6. California Specific Emissions Reduction Opportunities

Opportunities specific to California have been investigated by several independent parties. The CCAP (2005) study found that nearly 2 MMTCO2e could be reduced annually from measures costing less than $30 per metric ton (1.8 MMTCO2e in 2010 and 1.9 MMTCO2e in 2020). One-half (over one MMTCO2e) of the annual reductions would be obtained from measures that would produce a net cost savings, including the

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use of limestone Portland cement (0.6 MMTCO2e and 0.7 MMTCO2e in 2010 and 2020, respectively). Blended cements would account for about 0.7 MMTCO2e in 2010 and 2020, at a cost of less than $5 per metric ton. An additional 0.18 MMTCO2e/year of reductions could be achieved cost effectively by replacing coal with waste tire as a boiler fuel, but this option is not included because local community opposition makes it an unlikely option. Using similar data, an independent economic analysis estimates that emissions reductions by the cement industry accounting for 2.5% of statewide carbon emissions would have small, but negative macroeconomic effects (Roland-Holst, 2006).

In their comprehensive survey of the industry and management practices, Coito et al (2005) identified three general opportunities for reduced energy use:

1. *Operations and maintenance (O&M)*: finds that primary emphasis is on maximizing production through continuous operation, and less emphasis on minimizing costs and better efficiency.

2. *High efficiency equipment/processes*: self explanatory

3. *Controls*: Key opportunities for improved process controls involve clinker production and finish grinding, as well as operation of compressed air systems.

An interview with four "key plant managers" representing 5 plants revealed the following relevant information (Table 3.3):

- Managers believed the following factors to be critical to their businesses success: environmental regulations, market conditions, and energy costs….but implementing energy cost savings was less important.

- One reported "maintaining consistent production and product quality is the overriding concern. Although everyone at the plant is aware of energy […] we have limited operating staff[…] Also, the plant must remain in production as much as possible. The interruptions and coordination required for retrofits can also restrict consideration of energy retrofits."

- Managers demanded very high returns to justify capital investments- 1 to 1.5 years for low and 2-3 for high efficiency plants.

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- Two managers claimed to have policies in place to ensure higher energy efficiency on new investments, one demanded that new investments at least maintain standards, and one had no policy in place. Only 1 plant had an employee designated to monitoring energy efficiency.

Key limitations to greater efficiency were specified: limited energy efficient capital availability, production concerns (interrupting production), limited staff time (top priority to "keep things running"),  concerns about reliability of new investments or overhauls etc. "The smaller energy-efficiency items at these facilities can amount to fairly large savings but don't get addressed because they are considered a hassle."

**Table 5.  Rating of Key Business Factors**
**(0 = Unimportant, 5 = Extremely Important)**

| Business Factors | Average Ranking |
|---|---|
| Meeting regulatory requirements (such as environmental requirements) | 5.0 |
| Meeting your production schedule | 4.5 |
| Maintaining product quality and consistency | 4.3 |
| Keeping up with new or shifting market demands | 3.3 |
| Having a reliable, high quality supply of electricity | 3.3 |
| Maintaining your market niche | 2.5 |
| Keeping up technologically with competitors | 2.3 |
| Maintaining a happy and productive staff | 2.3 |
| Identifying and implementing cost saving measures | 1.3 |

Source: Coito et al, 2005

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Coito et al summarize their findings in this way: “In general, the tone of interview was that managers were dedicated to ensuring a smooth production process and didn’t have the time nor resources to give serious concern to energy efficiency.”

## 4.7. Individual Plant Survey

A plant by plant review of the industry reveals diversity of scale and some product characteristics, but the primary drivers of capacity use and cost do not appear to be very heterogeneous across this industry. Twelve cement plants operate in California, eleven of which are integrated plants, operating both kilns and grinding mills. One plant operates only grinding mills. Eleven produce grey cement, and one produces white. Twenty-seven percent of integrated plants produce at least some blended cement. Ninety one percent (10) of plants had an onsite quarry. Sixty four percent (7) had precalciners and nine percent (1) had preheaters.

Thirty six percent (36%) of plants (4) used some quantity of waste fuel, and eighty five percent of kilns used coal as their primary fuel. Mean kiln inception year was 1969 with a standard deviation of seventeen (17) years. Median kiln vintage was 1962 while mode kiln vintage was 1981. The most recent kiln renovation was 2001, though Texas Industries Oro Grande plant has contracted to begin construction on a new kiln. The oldest kiln was from 1948.

Average Kiln Age weighted By tonnage is 1983. Average vintage of kiln, omitting Texas Industries Crestmore ll and Oro Grande (outliers) was 1982. Seventy-three (73%) percent of plants had kilns from 1980 or later, up to eighty-two (82%) including the planned Oro Grande plant. Average tonnage per kiln was 620 (thousand tons).

According to confidential sources at the Energy Institute, kilns are estimated to be operating at near 100% capacity due to chronic cement shortages. Private discussion with Hendrik Van Oss reinforced this impression, though his 2004 report related levels closer to 90% (Personal…Van Oss, 2006; Van Oss, 2004).

The following table summarizes the salient structural features of California’s cement production facilities.

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## Table 3.2: Inventory of California Cement Facilities

**1. Mitsubishi Cement Corporation 5808 State Hwy. 18 Lucerne Valley CA 92356**
**H. O. Biggs (760) 248-7373**
**http://www.mitsubishicement.com/ (not active)**
**http://www.mitsubishicorp.com/en/network/us/america.html**
Type of Plant: Integrated
Type of Cement: Grey
Primary Fuel: Coal
Precalciner (C) Preheater (X) Neither (N): C
Roller Press: Y
Number of Kilns: 1
Average Age of Kilns: 1982
Most Recent Kiln: 1982
Mean Kiln Clinker Capacity/Production (Thousand Tons): 1543
Total Kiln Clinker Capacity/ Production (Thousand Tons): 1543
Number of Mills: 4
Average Age of Mills: 1965.5
Most Recent Mill: 1982
Mean Mill Cement Capacity (Thousand Tons): 446.75
Total Mill Cement Capacity (Thousand Tons): 1787

**2. CEMEX 16888 North E. Street Victorville CA 92392**
**Craig Gotro (760) 381-7600**
**http://www.cemexusa.com/index.asp**
**http://finance.yahoo.com/q/pr?s=CX**
Type of Plant: Integrated
Type of Cement: Grey
Primary Fuel: Coal
Precalcinor (C) Preheater (H) Neither (N): X
Roller Press: Y
Number of Kilns: 2
Most Recent Kiln: 2001
Average Age of Kilns: 1992.5
Mean Kiln Clinker Capacity/Production (Thousand Tons): 1363.5
Total Kiln Clinker Capacity/ Production (Thousand Tons): 2727
Number of Mills: 5
Average Age of Mills: 1974.8
Most Recent Mill: 2001
Mean Mill Cement Capacity (Thousand Tons): 630.8
Total Mill Cement Capacity (Thousand Tons): 3154

**3. Hanson Permanente Cement 24001 Stevens Creek Blvd Cupertino CA 95014**
**Stewart B. Smith (408) 996-4271**
**http://www.hanson.biz/**
**http://biz.yahoo.com/ic/110/110781.html**
Type of Plant: Integrated
Type of Cement: Grey
Primary Fuel: Coal
Precalcinor (C) Preheater (H) Neither (N): C
Roller Press: Y
Number of Kilns: 1
Average Age of Kilns: 1981
Most Recent Kiln: 1981
Mean Kiln Clinker Capacity/Production (Thousand Tons): 1497
Total Kiln Clinker Capacity/ Production (Thousand Tons): 1497
Number of Mills: 3
Average Age of Mills: 1992.67
Most Recent Mill: 1996
Mean Mill Cement Capacity (Thousand Tons): 604.67
Total Mill Cement Capacity (Thousand Tons): 1814

**4. California Portland Cement Co. 9350 Oak Creek Road Mojave CA 93501**
**Bruce Shafer (805) 824-2401**
**http://www.calportland.com/**
**http://www.calportland.com/Mojave/Mojave.htm**
California Portland Cement sells 6 million tons of cement, 3 million yards of concrete, and 8 million tons of aggregates, which are worth nearly $1 billion in annual sales.
Reduced energy use by 3% in 2004 and overall carbon emissions by 27,200,000.
"The California Portland Cement Company's Mojave Plant employs 150 people to extract limestone and produce cement at a 9,000 acre site (Center…Interpretation)."
Type of Plant: Integrated
Type of Cement: Grey
Primary Fuel: Coal
Precalcinor (C) Preheater (H) Neither (N): C
Roller Press: N
Number of Kilns: 1
Average Age of Kilns: 1981
Most Recent Kiln: 1981
Mean Kiln Clinker Capacity/Production (Thousand Tons): 1363
Total Kiln Clinker Capacity/ Production (Thousand Tons): 1363
Number of Mills: 7
Average Age of Mills: 1961.57
Most Recent Mill: 1996
Mean Mill Cement Capacity (Thousand Tons): 1511
Total Mill Cement Capacity (Thousand Tons): 215.86

**5. Texas Industries Inc. 19409 National Trails Hwy. Oro Grande CA 92368**
**http://www.txi.com/**
**http://finance.yahoo.com/q?s=txi&d=v2**
"A 50-year-old 1.3 million ton per year cement plant that operates seven kilns is being replaced by a new 2.3 million ton per year single kiln line. The kiln line includes a 400-foot-tall preheater/precalciner and is being supplied by equipment vendor Polysius Corp. of Georgia." (The…Report, 2006) Confirmed by personal

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interview with H. van Oss (Personal...Van Oss, 2006)
Type of Plant: Integrated
Type of Cement: Grey
Primary Fuel: Coal
Precalcinor (C) Preheater (H) Neither (N): N
Roller Press: N
Number of Kilns: 7
Average Age of Kilns: 1952.29
Most Recent Kiln: 1959
Mean Kiln Clinker Capacity/Production (Thousand Tons): 155
Total Kiln Clinker Capacity/ Production (Thousand Tons): 1085
Number of Mills: 5
Average Age of Mills: 1952.2
Most Recent Mill: 1960
Mean Mill Cement Capacity (Thousand Tons): 156.4
Total Mill Cement Capacity (Thousand Tons): 782

**6. National Cement Co. Of California Highway 138, 5 Miles East of I-5 Lebec CA 93243**
**Byron McMichael (661) 248-6733**
**http://www.vicat.com/**
Type of Plant: Integrated
Type of Cement: Grey
Primary Fuel: Coke
Precalcinor (C) Preheater (H) Neither (N): C
Roller Press: N
Number of Kilns: 1
Average Age of Kilns: 1999
Most Recent Kiln: 1999
Mean Kiln Clinker Capacity/Production (Thousand Tons): 1033
Total Kiln Clinker Capacity/ Production (Thousand Tons): 1033
Number of Mills: 3
Average Age of Mills: 1980.67
Most Recent Mill: 2001
Mean Mill Cement Capacity (Thousand Tons): 538
Total Mill Cement Capacity (Thousand Tons): 1614

**7. Lehigh Southwest Cement Company 13573 Tehachapi Blvd. Tehachapi CA 93561**
**Ed Watamaniuk (661) 822-4445**
**http://www.lehighsw.com/**
Type of Plant: Integrated
Type of Cement: Grey
Primary Fuel: Coal
Precalcinor (C) Preheater (H) Neither (N): C
Roller Press: N
Number of Kilns: 1
Average Age of Kilns: 1991
Most Recent Kiln: 1991
Mean Kiln Clinker Capacity/Production (Thousand Tons): 958
Total Kiln Clinker Capacity/ Production (Thousand Tons): 958
Number of Mills: 2
Average Age of Mills: 1981.5
Most Recent Mill: 1992
Mean Mill Cement Capacity (Thousand Tons): 408
Total Mill Cement Capacity (Thousand Tons): 816

**8. Cemex Davenport 700 Highway One Davenport CA 95017**
**Satish H. Sheth (831) 458-5700**
**http://www.cemexusa.com/index.asp**
**http://www.cemexusa.com/ce/ce_pl_da.html**
**http://finance.yahoo.com/q/pr?s=CX**
Type of Plant: Integrated
Type of Cement: Grey
Primary Fuel: Coal
Precalcinor (C) Preheater (H) Neither (N): C
Roller Press: N
Number of Kilns: 1
Average Age of Kilns: 1981
Most Recent Kiln: 1981
Mean Kiln Clinker Capacity/Production (Thousand Tons): 812
Total Kiln Clinker Capacity/ Production (Thousand Tons): 812
Number of Mills: 2
Average Age of Mills: 1981
Most Recent Mill: 1981
Mean Mill Cement Capacity (Thousand Tons): 428.5
Total Mill Cement Capacity (Thousand Tons): 857

Note: Purchased by Cemex from RMC for 5.8 billion in June 2004. Made CEMEX the world's leading concrete supplier. "An improved motor system allowed for savings of 2.4 million kwhs in 2004, and 1260 increase in tonnage per months. Because the newer motors have higher efficiencies (95%) than the ones they replaced, the blowers and cement pumps require less power to operate. Measurements of the motors' energy consumption show that the project has reduced energy use by 2,097,000 kWh and saves $168,000 in energy costs annually. These figures are consistent with the MotorMaster+ estimates. In addition, the plant is saving $30,000 in annual maintenance costs. A rebate from PG&E reduced the total project costs to $134,000, for a simple payback of 8 months (Cemex: Cement Manufacturer)."

**9. California Portland Cement Co. 695 South Rancho Ave Colton CA 92324**
**D. M. Robertson (909) 825-4260**
**http://www.calportland.com/**
**http://www.calportland.com/General/cement.htm**
Type of Plant: Integrated
Type of Cement: Grey
Primary Fuel: Coal
Precalcinor (C) Preheater (H) Neither (N): N

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Roller Press: N
Number of Kilns: 2
Average Age of Kilns: 1962
Most Recent Kiln: 1962
Mean Kiln Clinker Capacity/Production (Thousand Tons): 340
Total Kiln Clinker Capacity/ Production (Thousand Tons): 680
Number of Mills: 4
Average Age of Mills: 1971
Most Recent Mill: 1980
Mean Mill Cement Capacity (Thousand Tons): 268
Total Mill Cement Capacity (Thousand Tons): 1072

**10. Lehigh Southwest Cement Company 15390 Wonderland Blvd. Redding CA 96003**
**James E. Ellison (530) 275-1581**
http://www.lehighsw.com/
Type of Plant: Integrated
Type of Cement: Grey
Primary Fuel: Coal
Precalcinor (C) Preheater (H) Neither (N): C
Roller Press: N
Number of Kilns: 1
Average Age of Kilns: 1981
Most Recent Kiln: 1981
Mean Kiln Clinker Capacity/Production (Thousand Tons): 592
Total Kiln Clinker Capacity/ Production (Thousand Tons): 592
Number of Mills: 3
Average Age of Mills: 1966.67
Most Recent Mill: 1980
Mean Mill Cement Capacity (Thousand Tons): 206.34
Total Mill Cement Capacity (Thousand Tons): 619

**11. Texas Industries Inc., Crestmore II, Riverside CA**
**http://www.txi.com/**
**http://finance.yahoo.com/q?s=txi&d=v2**
Type of Plant: Integrated
Type of Cement: White
Primary Fuel: Oil
Precalcinor (C) Preheater (H) Neither (N): N
Roller Press: N
Number of Kilns: 1
Average Age of Kilns: 1959
Most Recent Kiln: 1960
Mean Kiln Clinker Capacity/Production (Thousand Tons): 51
Total Kiln Clinker Capacity/ Production (Thousand Tons): 102

Number of Mills: 1
Average Age of Mills: 1958
Most Recent Mill: 1958
Mean Mill Cement Capacity (Thousand Tons): 122
Total Mill Cement Capacity (Thousand Tons): 122

**12. Texas Industries Inc., Crestmore I, Riverside CA**
**http://www.txi.com/**
**http://finance.yahoo.com/q?s=txi&d=v2**
Type of Plant: Grinding
Number of Mills: 3
Average Age of Mills: 1960
Most Recent Mill: 1960
Mean Mill Cement Capacity (Thousand Tons): 248
Total Mill Cement Capacity (Thousand Tons): 744

## 4.8. How will Cement Manufacturers Respond to Adjustment Pressures?

The following key features of California's cement industry are relevant to the fate of its incumbent producers. Firstly, the demand for cement in California has remained high to the point that the industry reports supply shortages in each of the last three years (Cement Americas, 2004). This condition has persisted despite rising costs of fuel and transport, which have been passed on to consumers in the form of steeply increased prices, implying inelastic demand (Van Oss, 2004). From this experience one might infer that the size of the cement market in California should be relatively resilient to price increases induced by regulation, and that incentives to provide California with cement will remain strong. Still, various sources report that demand for cement has eased in recent months.

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Will cement plants leave the state in response to the higher production costs arising from GHG regulation? This is depends on two factors: cost control and pricing power. In the first case, firms will need to shift resources to offset increased emission costs, which can be done with investments in more efficient technology, carbon sequestration, or increases in other forms of process efficiency. In the second case, firms may be able to pass on some induced regulatory cost in the form of higher prices. An overview of industry evidence suggests that there may be scope for both kinds of adjustment to limit pressure on long term industry profit margins. In some cases, such as energy efficiency, the same investments that reduce GHG liability also reduce energy cost. Investments in blending technology also fall into this category.

Returning to the original question of firm viability, it appears unlikely that any producers will emigrate in the near term, though if costs were high enough some might shut down. In the short term, leaving the state would mean forsaking substantial fixed asset investments. Within the very near future, 82% of California cement plants will have kilns built in 1980 or later (Portland…A, 2004). Kilns from 1948 are still in operation today even though they produce much higher energy costs that their designers envisioned and they achieve only 10% the level of newer plants, indicating to the enduring value of such investments. To construct a plant with a capacity of 1 million tons annually costs near $300 million, and a 2 million ton plant runs near $450 million. Kiln conversion or renovation costs over $50 million (Personal…Van Oss, 2006).

Could cement plants, in the long run, leave the state as their investments depreciate? It is unlikely that they might move to other states. Firstly, this argument assumes that other states will not ultimately follow California in upgrading environmental standards. Secondly, though quarries are disseminated throughout the US, high and rising transportation costs provide significant incentives for cement plants to locate near markets. The vast majority locate within 200 to 300 miles of major markets (Regulatory…Rulemaking, 1998). Moreover, industry leaders do not consider many long distance transport options to be reliable, especially US railways, resulting in further costs of doing business (Cement Americas, 2004; Hanle, 2004, Regulatory Impact, 1998). Finally, a long history of rising costs in this industry has established a consistent trend, price appreciation in line with competitive rates of return, coupled with investments in more efficient technology. There is no particular

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reason that GHG policies, if these lead to higher costs for today's producers, will induce different behavior patterns.

Van Oss notes that a greater danger than cement production leaving the state is cement production leaving the country, as sea shipping costs can be dramatically less than other forms of transportation. Still, there are other shortcomings to importing, such as scheduling issues that might undermine its cost effectiveness. Van Oss also believes that plants might respond to regulation by investing less than they would otherwise. This is especially relevant for the current regulation as plants must always run at full capacity (using energy), but investments are usually made for meeting future, not current, demand levels.

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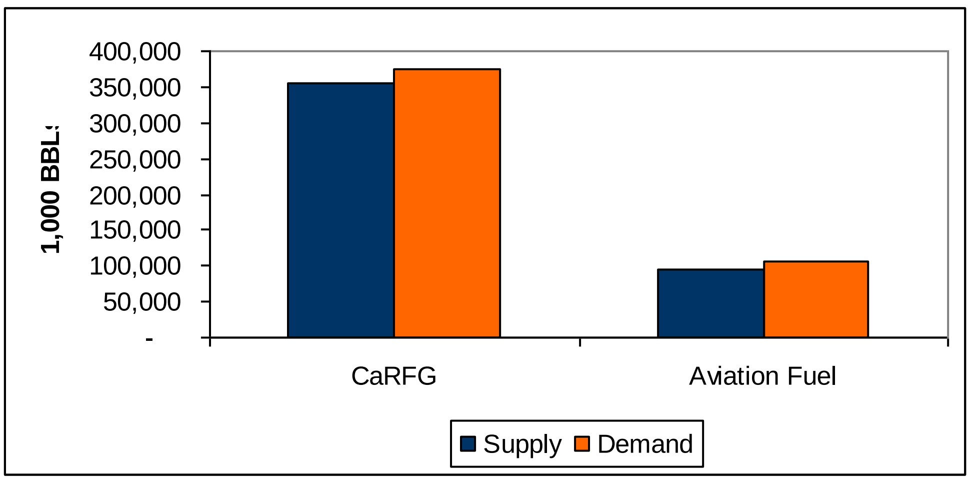
# 5. OIL REFINING

Oil refining is a major part of the California economy, both in terms of output and employment, but also in terms of demand for its final products. The refining sector accounted for 5% of California manufacturing sales in 1997, and the sector employs nearly 10,000 people.[26] On the demand side, California is the largest consumer of gasoline in the U.S. (11.3% in 2004), and second largest consumer of the country's jet fuel (17.7%); 40% of California's 2003 energy consumption was used for transportation.[27]

**Figure 5.1: California Gasoline and Aviation Fuel Supply and Demand**




Source: California reformulated gasoline and aviation fuel production data are from "Weekly Fuels Watch," CEC, online at http://www.energy.ca.gov/database/fore/index.html ; demand data are from Energy Information Administration (EIA) State Energy Profiles, online at: http://tonto.eia.doe.gov/state/state_energy_profiles.cfm?sid=CA#Con .

[26] Ernst Worrell and Christina Galitsky, 2004, "Profile of the Petroleum Refining Industry in California," LBNL-55450.

[27] Energy Information Administration (EIA) State Energy Profiles, online at: http://tonto.eia.doe.gov/state/state_energy_profiles.cfm?sid=CA#Con.

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At more than 2 million barrels (MBBLS) per day, California's crude oil distillation capacity ranks third among U.S. states. In-state oil refineries supply most of California's demand for refined oil products (Figure 5.1). Because of its higher product mix and California's more stringent environmental standards, oil refining is more energy-intensive in California than refining in other states. Oil refining consumes more energy than any other sector in California.[28] As a fossil fuel-intensive industry, oil refining is a major source of California's CO2 emissions.

## 5.1. California Refineries: Output

In 2006, 21 refineries operated in California, with a combined daily throughput of 2.022 million barrels of crude inputs. As Figure 5.3 shows, the 10 largest refineries accounted for nearly 84% of the state's total refining capacity, with the largest 5 accounting for 54%.

California's oil refining is concentrated in the Los Angeles Basin (LAB) and the San Francisco Bay (SFB) areas, with 6 of the state's largest 10 refineries in the LAB region and 4 in the SFB region (Table 1). As Figure 5.3 shows, the 7 largest refiners account for 90% of total state refining capacity.

[28] Worrell and Galitsky (2004).

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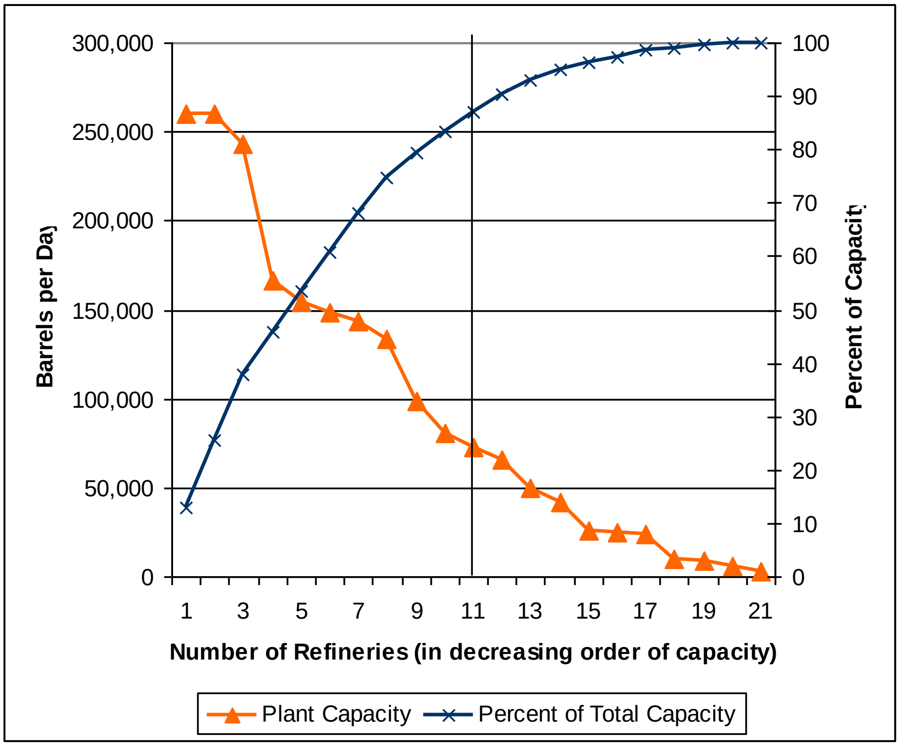
**Figure 5.3: Refining Capacity and Percent Capacity in California, 2006**




Source: "Oil and Petroleum in California," California Energy Commission website, online at: http://energy.ca.gov/oil/index.html.

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**Table 5.1: Refining Capacity in California by Region**

| Refinery | City | Capacity (BPD) | Region |
|---|---|---|---|
| BP West Coast Products LLC | Carson | 260,000 | LAB |
| Chevron 1 | El Segundo | 260,000 | LAB |
| Chevron 2 | Richmond | 242,901 | SFB |
| Tesoro, Golden Eagle | Rodeo | 166,000 | SFB |
| Shell | Martinez | 154,900 | SFB |
| ExxonMobil | Torrance | 149,000 | LAB |
| Valero | Benicia | 144,000 | SFB |
| ConocoPhillips, | Wilmington | 133,100 | LAB |
| Shell Oil Products US | Wilmington | 98,500 | LAB |
| Valero (Ultramar) | Wilmington | 80,887 | LAB |

Source: "Oil and Petroleum in California," California Energy Commission website, online at: http://energy.ca.gov/oil/index.html.

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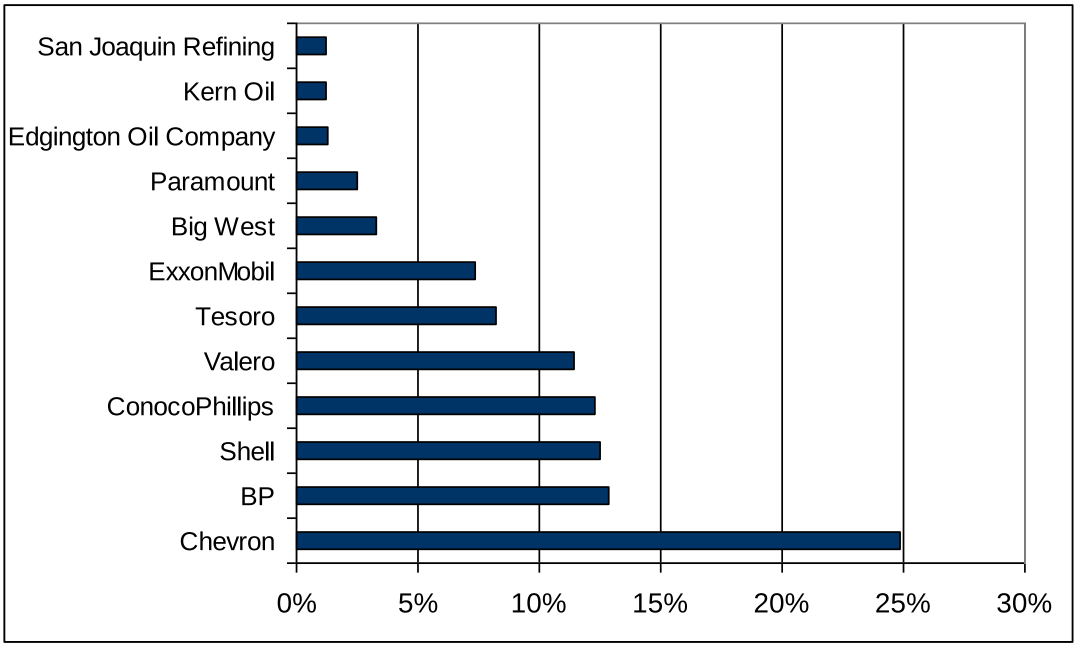
**Figure 5.3: Top Refiners in California, Percentage of State-wide Production**




Source: "Oil and Petroleum in California," California Energy Commission website, online at: http://energy.ca.gov/oil/index.html.

California crude inputs into and outputs from refining have remained relatively constant since 1999 (Figure 5.4). Refined outputs are typically classified into four categories: motor gasoline, jet fuel, distillate fuel, and residual fuel. Motor gasoline has accounted for about 60%, jet fuel for about 15%, and total distillates (mostly CARB diesel) for about 20% of the refined products tracked by the CEC. Reformulated gasoline accounted for 89 percent of total motor gasoline output over this time period.

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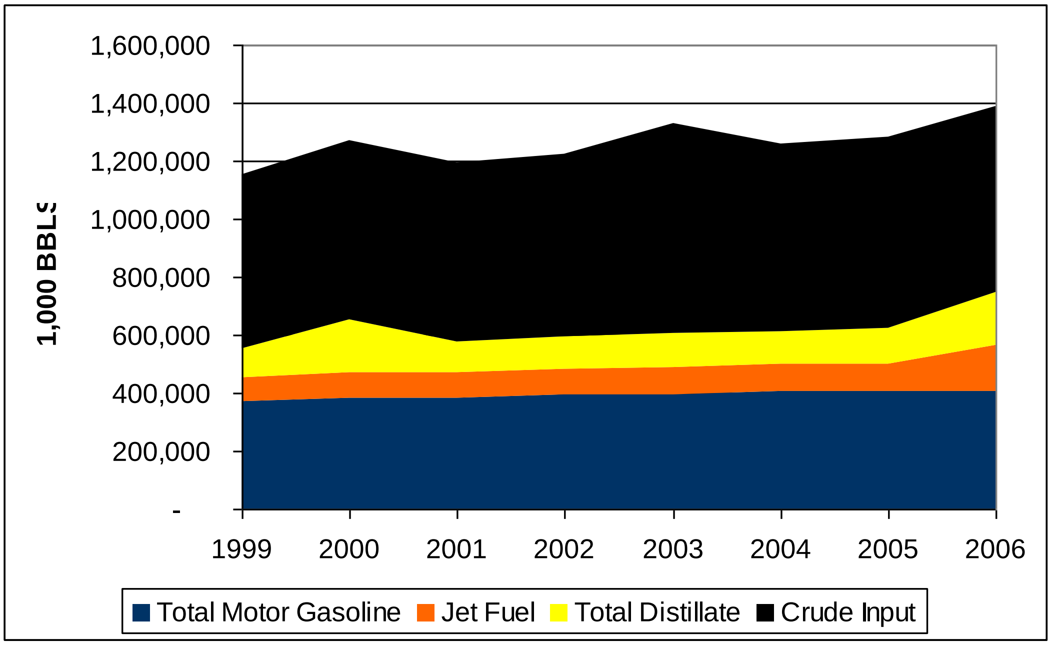
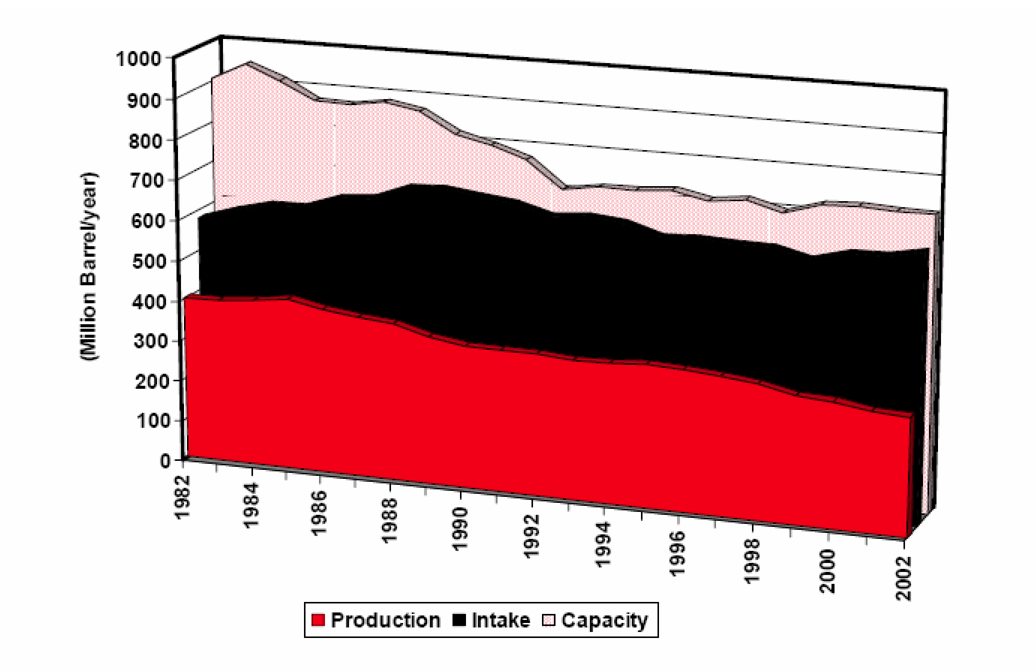
**Figure 5.4: Refined Oil Product Production in California, 1999-2006**




Source: "Weekly Fuels Watch," CEC.

**Figure 5.5: Refining Production, Intake, and Capacity in California, 1982-2002**




Source: Worrell and Galitsky (2004).

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California refining capacity has decreased by roughly 200 MBBLS/year since the early 1980s; no new refining capacity has been built in the U.S. since 1976. Combined with an increase of around 100 MBBLS/year in total refining output, this has led to an increase in capacity utilization, which stood at about 86% in 2002 (Figure 5.5).

Because California's transportation fuel requirements are different from other states' in the U.S., California, and the west coast more generally, is a relatively isolated market. Partly as a result, west coast refineries tend to have higher operating margins than other areas of the U.S. In 2000, the average operating margin of west coast refineries ($8/bbl) was roughly double that ($4) in other regions in the U.S.[29] With the increase in demand for transportation fuels over the past five years, refiners have profited from tight capacity. By 2005 net refining margins at the Tesoro Golden Eagle plant had increased to an estimated $12.32/bbl.[30]

## 5.2. California Refineries: Energy Use and CO2 Emissions

Oil refining is the largest energy consuming industry in California, and refining in California is more energy intensive than in other states because of refiners' product mix and California's environmental standards. As a result, the oil refining sector is a major source of state-wide $CO_2$ emissions, with an estimated 26 million metric tons (MMT) of CO2 emissions from fossil fuels by refineries in 2001.[31]

Refineries use large amounts of natural gas, electricity, and steam. Because oil refining creates a number of byproduct fuels and a fair amount of heat and high pressure steam, a non-trivial portion of refineries' fuels and electricity can be met through the refining process. Energy that is not produced in-house must be purchased, and refineries are among the largest users of electricity and natural gas in California.

[29] Worrell and Galitsky (2004).
[30] Based on SEC 10-K filings.
[31] David L. Wagger and Matthew Ogonowski, 2005, "Potential Reductions in GHG Emissions from Selected Industries in California," Presentation to the CEC.

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**Table 5.2: Estimated Energy Use in California Refining Processes**

| | Throughput barrels/cd | Fuel Tbtu | Steam Tbtu | Electricity GWh |
|---|---|---|---|---|
| **Desalter** | 1,978,132 | 0 | 0 | 32 |
| **CDU** | 1,978,132 | 46 | 27 | 322 |
| **VDU** | 1,156,155 | 18 | 20 | 132 |
| **Thermal Cracking** | 381,468 | 11 | -2 | 546 |
| **FCC** | 650,588 | 12 | 0 | 787 |
| **Hydrocracker** | 476,334 | 21 | 11 | 1794 |
| **Reforming** | 409,173 | 33 | 6 | 390 |
| **Hydrotreater** | 1,576,697 | 35 | 22 | 1282 |
| **Deasphalting** | 47,767 | 2 | 0 | 30 |
| **Alkylates** | 150,944 | 2 | 14 | 226 |
| **Aromatics** | 1,433 | 0 | 0 | 1 |
| **Asphalt** | 73,354 | 5 | 0 | 62 |
| **Lsomers** | 81,682 | 12 | 5 | 52 |
| **Lubes** | 30,953 | 11 | 0 | 161 |
| **Hydrogen** | 6,417,226 | 94 | 0 | 313 |
| **Sulfur** | 4,037 | 0 | -12 | 16 |
| **Others** | 0 | 13 | 7 | 950 |

Source: Worrell and Galitsky (2004).

The two most energy-intensive processes in Table 5.2 are hydrocracking and hydrotreating. Hydrocracking entails breaking heavier hydrocarbons (e.g., fuel oil) into lighter hydrocarbons (e.g., gasoline). Hydrotreating is used to remove contaminants (e.g., sulfur) from middle distillates. At a more general level, Table 5.2 illustrates two points. As refineries optimize their product mix to produce a greater share of lighter hydrocarbons, they increase energy use and most likely their $CO_2$ emissions. Similarly, as refineries adjust their processes to meet state federal and state environmental standards (e.g., by removing sulfur from diesel), they increase energy use and most likely their $CO_2$ emissions.

Calculating $CO_2$ emissions from the refining industry is complicated by the complex energy transactions involved in process optimization. Simpler emission factor and mass balance approaches do not necessarily provide meaningful emissions estimates. Similarly, little is known about the potential adjustment costs for refineries under a

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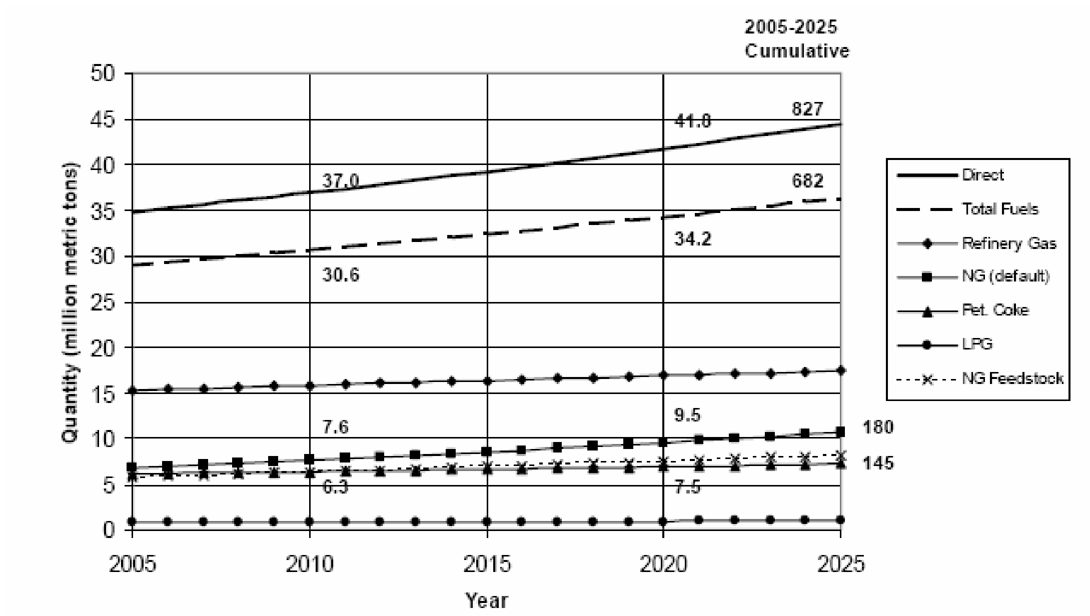
carbon constraint. A study commissioned by the CEC concluded that "abatement costs for CA refining could not be calculated at present."[32]

Figure 5.6 shows one estimate of $CO_2$ emissions from California's oil refining sector over the next two decades, with emissions increasing linearly. The slope of the refining sector's emissions curve will depend on scope for improving the energy efficiency of refining processes.

**Figure 5.6: Refinery Emissions and Energy Efficiency**




Source: David L. Wagger and Matthew Ogonowski, 2005, "Potential Reductions in GHG Emissions from Selected Industries in California," Presentation to the CEC.

[32] Wagger and Ogonowski (2005).

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## 5.3. Heterogeneity in California's Oil Refining Sector

The extent of heterogeneity, both in terms of adjustment potential and adjustment cost burden, in California's refining sector, while visible through refineries' different product mixes (see Table 5.3 for an example), remains unclear.

**Table 5.3: Refining Capacity, BP Carson and Chevron El Segundo Refineries**

| Process and Product | Unit Description | BP Carson | Chevron El Segundo |
|---|---|---|---|
| ALKYLATES | Production Capacity, Current Year (barrels per steam day except sulfur and hydrogen) | 15,000 | 33,500 |
| CAT CRACKING: FRESH FEED | Downstream Charge Capacity, Current Year (barrels per stream day) | 96,000 | 65,000 |
| CAT HYDROCRACKING, DISTILLATE | Downstream Charge Capacity, Current Year (barrels per stream day) | 43,000 | 49,000 |
| CAT REFORMING: HIGH PRESSURE | Downstream Charge Capacity, Current Year (barrels per stream day) | 42,000 | |
| CAT REFORMING: LOW PRESSURE | Downstream Charge Capacity, Current Year (barrels per stream day) | 10,000 | 49,000 |
| DESULFURIZATION, DIESEL FUEL | Downstream Charge Capacity, Current Year (barrels per stream day) | 20,000 | 60,000 |
| DESULFURIZATION, GASOLINE | Downstream Charge Capacity, Current Year (barrels per stream day) | 10,000 | |
| DESULFURIZATION, HEAVY GAS OIL | Downstream Charge Capacity, Current Year (barrels per stream day) | 90,000 | 72,000 |

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| | | | |
|---|---|---|---|
| DESULFURIZATION, KEROSENE AND JET | Downstream Charge Capacity, Current Year (barrels per stream day) | 10,000 | |
| DESULFURIZATION, NAPHTHA/REFORMER FEED | Downstream Charge Capacity, Current Year (barrels per stream day) | 60,000 | 77,500 |
| HYDROGEN (MMCFD) | Production Capacity, Current Year (barrels per steam day except sulfur and hydrogen) | 105 | 74 |
| ISOMERIZATION (ISOBUTANE) | Production Capacity, Current Year (barrels per steam day except sulfur and hydrogen) | 3,500 | 7,700 |
| OPERATING CAPACITY | Atmospheric Crude Distillation Capacity (barrels per stream day) | 260,500 | 273,000 |
| PETCOKE,MARKET | Production Capacity, Current Year (barrels per steam day except sulfur and hydrogen) | 11,400 | 20,000 |
| SULFUR (SHORT TONS/DAY) | Production Capacity, Current Year (barrels per steam day except sulfur and hydrogen) | 350 | 600 |
| THERM CRACKING, DELAYED COKING | Downstream Charge Capacity, Current Year (barrels per stream day) | 65,000 | 66,000 |
| TOTAL OPER CAP (PROJECTED, NEXT YEAR) | Atmospheric Crude Distillation Capacity (barrels per stream day) | 260,500 | 273,000 |
| TOTAL OPERABLE CAPACITY | Atmospheric Crude Distillation Capacity (barrels per stream day) | 260,500 | 273,000 |
| VACUUM DISTILLATION | Downstream Charge Capacity, Current Year (barrels per stream day) | 130,000 | 137,000 |

Source: EIA website, online at: *http://www.eia.doe.gov/oil_gas/petroleum/data_publications/refinery_capacity_data/refcap_historical.html*

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In the rest of this section, we examine the Tesoro Golden Eagle refinery in greater detail.

### 5.3.1. *Tesoro Golden Eagle*

Tesoro's Golden Eagle refinery is equipped with fluid catalytic cracking (FCC) (in the process of installing more efficient delayed cooking), Hydrocracking (HCU), Naphtha Reforming, Alkylation, Vacuum Distillation (VDU), Hydrotreating, and Fluid Coking capabilities. Golden Eagle has been specially designed to process heavier crude oil feedstocks such as those from Alaska's North Slope and California's San Joaquin Valley. In 2005, Tesoro received 58% of their crude oil input from domestic sources (23% from Alaska's North Slope) and 42% of total inputs from foreign sources (12% from Canada).

All heavy crude refined by Golden Eagle, (crude with API gravity less than 18 degrees) comes from domestic sources, found in Kern County, and San Joaquin Valley, California. Sulfur content is an important factor in determining refineries' energy consumption because sour crude (petroleum feedstock with sulfur content of 1% or more) requires treatment by the desalter. As Table 5.4 shows, 61.38% of Golden Eagle's feedstock contains a sulfur percentage grade of at least 1%. Fifty percent of inputs for Golden Eagle are middle distillates (Feedstock with API 18-36 degrees).

**Table 5.4: Tesoro, Golden Eagle Refinery, Input Composition**

| | %of total Imp | SULFUR | APIGRAVITY |
|---|---|---|---|
| **ECUADOR** | 3.38% | 1 | 29.2 |
| **NORWAY** | 4.71% | 0.2 | 32.5 |
| **YEMEN** | 4.85% | 0.6 | 30 |
| **ANGOLA** | 9.76% | 0.71 | 28.5 |
| **BRAZIL** | 4.17% | 0.77 | 20 |
| **KOREA, SOUTH** | 3.13% | 0 | 0 |
| **Domestic, California** | 35% | 1.24 | 17.5 |
| **North-Slope** | 23% | 1.1 | 29-29.5 |
| **Canada** | 12.00% | N/A | N/A |

*Note, Domestic inputs calculated based on available pipeline schematics, calculated as weighted average from source wells in Kern County, California.

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Golden Eagle's recent capital expenditures' reflect the capital-intensive nature of the refining industry. The afore-mentioned upgrade from Fluid Coker to Delayed Coker will be completed in the fourth quarter of 2007 at an estimated cost between $475 to $525 million. Capital expenditures in refining were 84.61% of total capital expenditures for Tesoro. Golden Eagle will not be affected by recent EPA standards relating to sulfur content in gasoline in their Golden Eagle refinery because of recent upgrades in sulfur treatment installations.

As can be seen in Table 5.5, 53.76% of Golden Eagle's outputs consist of California reformulated gasoline (CaRFG). Maintaining this product mix over the next decade will be challenging for Golden Eagle because a large share of its inputs consist of high sulfur crude of increasing viscosity from domestic sources (Kern County, and San Joaquin Valley). Refining more viscous feedstocks will require capital investment in equipment that can handle them.

**Table 5.5: Output statistics: Tesoro, Golden Eagle Refinery**

| | 2005 | | 2004 | |
|---|---|---|---|---|
| Gasoline and gasoline blendstocks | 93 | 53.76% | 96 | 59.26% |
| Diesel fuel | 49 | 28.32% | 38 | 23.46% |
| Heavy oils, residual products, internally produced fuel, and other | 31 | 17.92% | 28 | 17.28% |
| Total | 173 | | 162 | |

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# 6. CALIFORNIA CHEMICAL INDUSTRY

## 6.1. Overview

While the electricity, cement, and refinery industries are organized around a relatively small number of large and similar firms, the chemical industry is highly diverse and populated with both oligopolistic and competitive producer groups. [33] This industry is significant to California's economy, with 1544 firms employing 82,300 workers directly and more indirectly throughout the manufacturing sector, the chemical industry plays a key role in California's economy, especially in support of trade, business services, manufacturing, agriculture, and transportation. The Californian chemical industry exported about $3 billion in 1996, and had profits at an average of eight to nine percent, making it the sixth largest chemical producing state (California Energy Commission). There are over 1,500 chemical plants in California, the greatest number of chemical plants in the US, due to a larger number of smaller establishments and a different mix of specialty products. 52% are pharmaceutical companies, with a number of the nation's largest biotechnology and pharmaceutical companies found in the San Francisco Bay Area. Pharmaceutical and Medical manufacturing make up about 52% of the value of shipments in the California's chemical manufacturing industry, with values of over $12.5 Billion in 2000. This is followed by Soap, Cleaning, Compound and Toilet Preparation manufacturing with over $3 Billion; Paint, Coating and Adhesive and then Basic Chemical, both with over $2 Billion; Other Chemical Product with over $1.8 Billion; Resin, synthetic Rubber, and Artificial and Synthetic Fibers with over $1.2 Billion; and finally Pesticide, Fertilizer, and Other Agricultural Chemical manufacturing with over $500,000 (California Energy Commission).

Many of the top 25 chemicals produced in California are used in agricultural production. California's computer and electronics industry is also dependent on electronic chemicals and high performance plastics. There are over 1,500 chemical

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[33] This section draws heavily on the very informative industry survey by Galitsky and Worrell: 2004.

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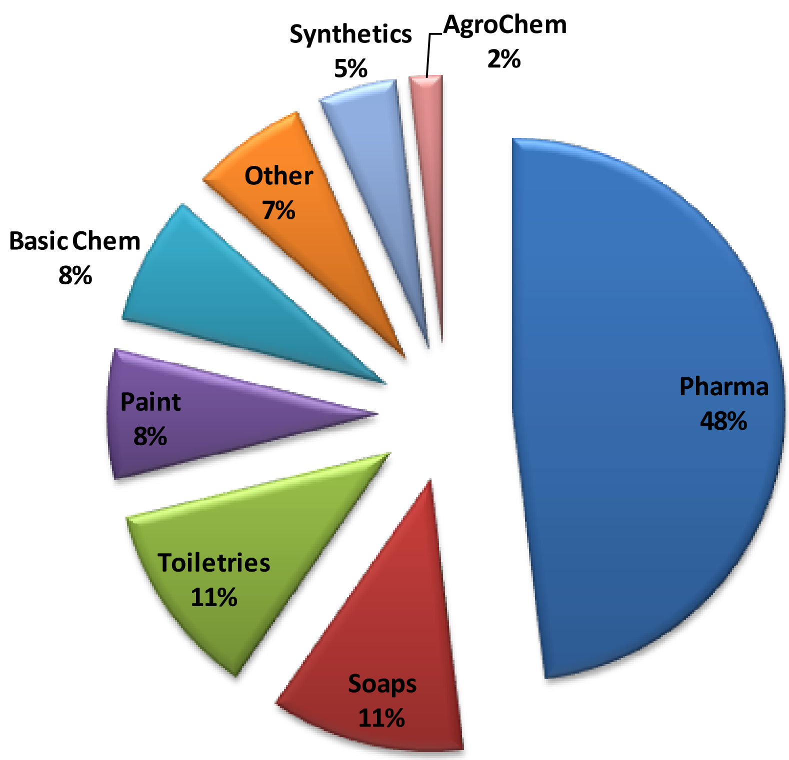
plants in California, by far the largest number for any state in the US, due to a larger number of smaller establishments and a different mix of specialty products. Just over half are pharmaceutical companies, including several of the nation's largest biotechnology and pharmaceutical companies can be found in Northern California.

**Figure 6.1: Value Composition of California Chemicals**

(source: Galitsky and Worrell: 2004)




California has much less focus on basic chemicals, rubbers and plastics and agricultural products than the U.S. as a whole, and much more on pharmaceutical products and other less energy-intensive high value added chemicals. The industry can be conveniently divided into seven segments, a description of which can be found at http://www.bls.gov/oco/cg/cgs008.htm. Pharmaceutical and Medical manufacturing make up about 52% of the value of shipments in the California's chemical industry, valued at over $12.5 Billion in 2000. This is followed by Soap, Cleaning, Compound and

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Toilet Preparation manufacturing with over $3 Billion; Paint, Coating and Adhesive and then Basic Chemical, both with over $2 Billion; Other Chemical Product with over $1.8 Billion; Resin, synthetic Rubber, and Artificial and Synthetic Fibers with over $1.2 Billion; and finally Pesticide, Fertilizer, and Other Agricultural Chemical manufacturing with over $500,000 (Figure). (California Energy Commission).This report focuses on the pharmaceutical and inorganic chemicals sub-sectors.

At the national level, the U.S. chemical industry is the second largest energy consumer among manufacturing sectors, after only petroleum refining. Energy costs represent an average of about 7% of industry value added, but vary widely across this diverse space of processes and products. Overall, the industry spent $16 billion on energy purchases in 2001, $6.4 billion on electricity, and $9.9 billion on fuels. About 10% of their use was a result of co-generation, a growing component of their energy portfolio.

Thus California's chemical industry has much more of a focus on pharmaceutical products and other less energy-intensive, high-value chemicals than the U.S. as a whole, and has implications for the consequences of carbon emissions caps, including the low risk of capital flight. This report focuses on the inorganic chemicals and pharmaceutical sub-sectors, as they represent the most diverse and the largest sub-sectors respectively.

## 6.2. Production Statistics

Inherently energy-intensive, chemical production consumed about 8% and 5% of California's manufacturing sector electrical and gas consumption respectively (Chemical Industry Council). The primary energy consumption of the chemical industry in California is estimated at 48 TBtu in 2000 (51 PJ), excluding hydrocarbon feedstocks from petroleum products. Differences in product mix mean a different, less energy intensive production structure than the U.S. average. Organic chemicals are not as prominent, which is significant for lower emissions in California, as they tend to consume energy heavily in production. In particular, California produces no carbon black, alkalis or chlorine. The most important energy users in the Californian chemical industry are inorganic chemicals (e.g. industrial gases, borax) and pharmaceuticals.

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The inorganic chemical industry accounts for nearly 50% of the chemical sector's total energy use in California.

The pharmaceutical sub-sector has experienced the largest growth rate in the last few years, fueled by the discovery of new drugs and advances in the understanding of diseases. California contains some of the largest pharmaceutical companies. The San Francisco Bay Area, in particular, is home to such larger companies as Genentech, Lifescan, Alza Corp, Chiron and Bayer. In 1997, there were over 350 soap and cleaning product manufacturers in California, more than any other state in the US. They include Allergan, Inc, by far the largest producer of toiletries in California, followed by Merle Norman Cosmetics, Inc., Packaging Advantage Corp., and The Color Factory, Inc. Neutragena produces the most soaps and detergents. There were over 250 paint manufacturers in California, more than any other state in the US. They include Kelly-Moore Paint Co., Inc., by far the largest producer of paints in California, followed by Frazee Industries, Inc., Behr Process Corp., DUNNEdwards Corp., and Vista Paint Corp.

*Inputs (fuels, etc)*

Electricity and natural gas account for over 70% of the energy used by the chemical industry. The main fuel used in the chemical manufacturing sector is natural gas, followed by coal. Liquefied petroleum gases account for much of the fuel used as feedstocks, followed by natural gas. Electricity is also used in pump, fan and compressed air systems, materials processing, and refrigeration. The chemical industry has been an important cogenerator, generating about 20% of its electricity use in 2001.

*Outputs*

Pharmaceutical and medicinal products include pills, vaccines, diagnostic testing and diabetic products, as well as nutritional and herbal supplements and vitamins, food supplements and biotech products like proteins, enzymes, reagents, instruments, cell cultures and media.

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Soap and cleaning products include soaps, detergents, softeners, shoe and lens cleaners, personal care, beauty products and toiletries, air fresheners, automotive waxes and polishes.

Paint products include a variety of coatings like ink, plastic, powder, wood furniture, concrete, polyurethane and epoxy, industrial paints, indoor and outdoor paints; aerosols, dyes, lacquers, clays, pigments, cement chemicals, and laminations.

Inorganic chemical production mainly consists of industrial gas production (hydrogen, nitrogen, oxygen, argon), dyes and pigments, and other basic chemical products such as bleach, borax, sulfuric acid, plating materials, high temperature carbons and graphite products and catalysts. (Adapted from Worrell and Galitsky, 2004)

*Technology*

Areas with significant energy consumption:

Separations, chemical synthesis and process heating are the major energy consumers in the chemical industry. Separations account for 40 to 70% of capital and operating costs in chemical plants. Separation processes include distillation, extraction, absorption, crystallization, evaporation, drying, steam stripping, cracking, and membranes. The most widely used is distillation, accounting for up to 40% of the industry's energy use (Humphrey, 1997). Chemical synthesis consists mainly of catalytic reactions, as well as polymerization, hydration, hydrolysis and electrolysis (U.S. Department of Energy-OIT, 1999).

Worrell and Galitsky (2004) explain the areas of development for energy reduction relevant to the chemicals industry. They relate to process control and management, process optimization and integration, energy recovery, catalysts, reactor design, biotechnology, separations, combustion technology, clean rooms, utilities, and power generation. For a summary of Technology Development Directions, see Table ES-1, Appendix A. While some of the ideas are currently in execution by firms in the industry, other areas remain unexplored, leaving room for energy reduction in the

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chemicals sector. Also, some areas such as in energy recovery lie outside of chemical plants' control.

In terms of process control and management, the key area of importance for the chemical industry in California is the integration and optimization of batch processes. Special control technologies have been developed to schedule and optimize the use of batch processes in the pharmaceutical industry. Various vendors have developed technology just for this purpose, and are applied by many pharmaceutical companies. For example, Genentech has purchased technology developed by Agilisys to control one of its production facilities. Separation processes are important energy users. An extensive roadmap has been prepared by the American Institute of Chemical Engineers and U.S. Department of Energy (Adler et al., 2000). Challenges are found in the current regulations and measurement of clean room performance, and the need for improved design and operation tools (Tschudi et al., 2002). Integration and optimal design of the different elements of a clean room will likely result in substantial energy savings. Design groups in e.g. California, Ireland and Finland look at different designs and applications. The new Genentech facility in Vacaville (California) has adopted several incremental improvements in clean room design and realized annual energy savings of over $500,000.

In California, the main products produced in the inorganic chemicals sector are hydrogen, nitrogen, oxygen, argon, borax and bleach. California produces no chlorine gas, an energy intensive process. Nitrogen, oxygen and argon all involve air separation processes. The cost of power is a major component of the total cost of industrial gas products. It can be two-thirds of the total cost of manufacturing. Large air separation plants consume thousands of kilowatts every hour. Most hydrogen plants are operated by a third party at or near a petroleum refinery. Most of the hydrogen is sold to the refinery, and used for conversion processes in the refinery. At least four refineries have outsourced hydrogen production: San Joaquin Refinery (Bakersfield, 3.5 million cubic feet per day (MMcfd) H2), Shell (Wilmington, 55 MMcfd H2), Tesoro (Golden Eagle, 31 MMcfd H2) and Valero (Wilmington, 57 MMcfd H2). The energy consumption for these hydrogen units is estimated at 14.5 TBtu natural gas  assuming 89% capacity utilization, based on the refinery average) and 46 MWh electricity (derived from Worrell et al., 2000).

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Chemical plants supplying industrial gases to these refineries may find it not in their interests to relocate in response to the carbon emissions caps, if the contribution to their revenue from this demand is significant. Also, there is untapped potential to reduce energy usage, and hence emissions, as will be elaborated later.

The pharmaceuticals industry spans a spectrum of activities from the research and development associated with new and innovative drugs to the mass-production of generic and over-the-counter medicines. The output product must meet stringent specifications and be produced in the shortest time possible, at minimal cost. The industry is more research intensive than most other industries, and therefore much effort takes place at a small scale. The pharmaceutical manufacturing process must maintain the highest quality and safety standards. Hence it can benefit overall from improvements in process management, which can reduce energy usage as well and hence, emissions. Table 2 in the Appendix shows the estimated energy use for the pharmaceutical industry as a whole, categorized by end use and by activity area. These estimates do not refer to any particular plant, nor do they attempt to estimate the energy use at a "typical" pharmaceutical plant. In addition, Table 2 shows the main energy uses for each activity area and end use category. This list may not apply to all facilities nor is it assumed to be exhaustive.

The main energy using processes in the pharmaceutical industry are HVAC, including the clean room and equipment to maintain the production environment needs for pharmaceutical production, including heating, cooling, ventilation, air conditioning and air dehumidification. Clean room energy use in the pharmaceutical industry is estimated at 660 GWh (Tschudi et al., 2002), representing a very large part of the total electricity use in the pharmaceutical industry. This includes electricity use for cooling and heating the airflow into the clean rooms. As mentioned above, integration and optimal design of a clean room can result in substantial energy savings, as shown by Genentech's example. It is in pharmaceutical firms' interests to invest in such technology to reduce energy usage, an alternative to relocating to avoid the carbon emissions caps, as it can lead to reduced costs.

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*Areas with potential for energy use reduction:*

One of the most promising pathways to simultaneously reduce energy use and capital costs is process intensification.

Catalysts are key to the conversion and processing efficiency of all conversion processes in the chemical industry. The major energy using processes in California using catalysts are hydrogen production and plastic and resin manufacture, while specialized catalysts may be used in the pharmaceutical industry. Of special interest to the fine chemicals industries in California, is the area of biocatalysts.

Biotechnology is a primary driver of the high-value products of the California chemical industry. Although the total energy consumption of the pharmaceutical industry in California is limited, it contributes to about 50% of the value of shipments, making it an important area. While some of the issues particular for biotechnology development have been addressed in IOF roadmaps on alternative reaction engineering (Klipstein and Robinson, 2001) and alternative media (Breen, 1999), there is no single place where the main R&D needs and directions in biotechnology development, relevant for the Californian chemical industry, have been discussed.

Combustion is key in many of the processes used in hydrogen production and other processes in the organic and inorganic chemical industries. Boilers, furnaces and process heaters all apply burners to efficiently generate heat to produce steam, electricity and heat. Burner development is challenged by many issues. Foremost are challenges to reduce emissions from burners (i.e. NOx, CO, PM), as well as to increase the heat transfer and combustion efficiency of the burner. Other challenges include fuel flexibility, robust operating controls, improved safety, reliability and maintenance and lower costs (US DOE-OIT, 2002b). Small changes in the efficiency of combustion systems may provide large energy cost savings. Also, the use of low-NOx burners may result in indirect capital and energy savings, as it avoids the use of selective catalytic reduction. Hence, combustion technology is still an important R&D area with potential for new technologies.

As a large part of energy use in the pharmaceutical and other chemical industries is used in motors and other utilities, it becomes an important area for energy efficiency improvement. New technology development in pumping (e.g. dry vacuum pumps),

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power technology (e.g. adjustable speed drives and power electronics) and compressors can result in direct energy savings. The relative high power costs in California make these new technologies attractive.

The chemical industry is a large user of cogeneration or Combined Heat and Power production (CHP). The chemical industry is also identified as one of the industries with the largest potential for increased application of CHP (Onsite, 1997).

With these potentialities for energy usage reduction in sight, there exists room for chemical plants to adjust operations in order to comply with the new bills passed, while saving on significant power costs as well. However, these R&D areas present added expenditure for firms as well. There are examples of chemical plants being built with new energy-saving technologies. This may be due to the current and growing importance of pharmaceuticals in California, with strong demand and an ideal location for such facilities present. The low energy intensity of production also means that the carbon emission bills passed should not have too adverse effect on costs of chemical plants to do with adjusting to meet the carbon emission caps.

*Area of potential development that lies outside of chemical industry's control:*

Natural gas is an expensive energy input in the refinery process, and lately associated with large fluctuation in prices (especially in California). The major technology developments in the hydrogen management within the refinery are hydrogen process integration (or hydrogen cascading) and hydrogen recovery technology. Revamping and retrofitting existing hydrogen networks can increase hydrogen capacity between 3% and 30% (Ratan and Vales, 2002). But as the use of hydrogen is increasing, especially in Californian refineries, the value of hydrogen is more and more appreciated. It can be used for new and retrofit studies. Although this will result in reduced hydrogen production needs in the chemical industry the main opportunities are found in the petroleum refinery, and not in the hydrogen plant itself.

Whether inorganic chemical producers find it advantageous to relocate production depends significantly on demand from refineries, and the latter in turn will reconsider their production in light of the carbon bills passed too. The diverse nature of this sub-sector means that demand arises not just from refineries, but from other users of inorganic chemicals as well. Hence it may be in firms' interests to implement changes

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to reduce energy usage in production and hence emissions, rather than relocate their capital. (Information on Technology Development Areas adapted from: http://repositories.cdlib.org/cgi/viewcontent.cgi?article=3580&context=lbnl )

*Implications:*

The substantial and growing pharmaceutical sub-sector shows no sign of slowing down production, and the relatively low energy intensity of its processes means emissions can be kept low, with adjustments made for improvements in production operations, as seen in Genentech's case and other new plants being constructed in California currently. Since California does not produce heavily energy-intensive inorganic chemicals such as carbon black, the sub-sector may not face significant problems in adjusting to the new carbon bills passed. This is somewhat dependent on the petroleum refineries' reaction to the bills passed too. Other manufacturers in California should be seeking ways to improve their production processes too, as power is costly in California, and it is in firms' interests to reduce energy usage, even though the other sub-sectors do not tend to be major energy consumers.

*Significant emissions*

There is no publicly available data on energy consumption in chemical plants in California. However, the Chemical Energy Commission has provided data on electricity and gas use for the chemicals industry from 1990 to 2001 by SIC code. Unfortunately, much of the data from the CEC is categorized as "2800", or chemicals industry, not classified into sub-sectors. Figure 20 in the Appendix shows the electricity use by sub-sector in California for the year 2001. Clearly inorganic chemicals and pharmaceuticals are important electricity consumers in the California chemical industry. Unlike the U.S., however, the organic chemicals sub-sector is not a major electricity consumer.

Based on the method employed in the past (Elliott et al., 2003), a theoretical electricity distribution is estimated for the chemicals sector in California based on the value of shipments in California and U.S. trends for electricity use in the chemicals

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sector. Given a sub-sector's value of shipments in California, electricity use for that sub-sector is calculated based on the electricity that share represents on average in the U.S. Using U.S. data on electricity intensities of the chemical sub-sectors to predict electricity use for the California chemicals sector overestimates the electricity used in the organic chemicals sub-sector by approximately a factor of 16, and may underestimate the electricity used in the pharmaceuticals industry. This overestimation of the electricity use in the organic chemicals sub-sector is due, at least in part, to the fact that the plants in California do not produce energy-intensive petrochemical commodities like plants in the U.S., decreasing the electricity intensity compared to the U.S average. Figure 21 shows the trend in electricity use over the past decade for the chemicals industry in California. Electricity use has steadily increased from 1990 to 2000, rising by 16% over the 10-year period. Figure 22 shows the gas use by sub-sector in California for the year 2001. Unfortunately, most of the data is classified as chemicals, and not specified by sub-sector. Of the remaining data, the inorganic and pharmaceutical sub-sectors are the most important gas users. Figure 23 shows the trend in natural gas use over the past decade for the chemicals industry in California. Following a large drop in use in the early 1990s, natural gas use has remained flat since 1993. Figure 24 summarizes the estimated primary energy consumption of the chemical industry in California. A uniform efficiency for power generation of 46% has been used for the whole period to estimate the primary energy consumption for power generation, following the efficiency definitions as adopted by the International Energy Agency (IEA). This is substantially higher than the national average, due to a higher penetration of more efficient natural gas based power stations and renewable energy sources in California, when compared to the rest of the country. Table 1 provides the breakdown by sub-sector (three-digit SIC).

As discussed, there is room for reduction in electricity and gas consumption in the two important sub-sector consumers of pharmaceuticals and inorganic chemicals. The high cost of power is an incentive for firms to do so, and may outweigh costs of R&D in such an enterprise. (Adapted from Worrell and Galitsky, 2004)

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*Balance Sheets*

A survey of large manufacturers in the other chemical sub-sectors shows growth in size of firm, facility and services offered. The firms covered are Genentech, Johnson & Johnson parent company of Lifescan, Inc and Alza Corp), Novartis (parent company of Chiron), Bayer, Pfizer, and Allergan. The pharmaceutical companies generally face challenges of competing pharmaceutical firms, pharmaceutical divisions of chemical companies, and biotechnology companies. Loss of market share, reduced utilization or products, and/or lower prices, even for products protected by patents, can result from the introduction of new competitive products or follow-on biologics or new information about existing products (Genentech Inc, 2005). Costs include expenditures for environmental compliance and protection. They do not tend to be significant. For example, Genentech's expenditures for compliance with environmental laws "have not had, and are not expected to have, a material effect on our capital expenditures, results of operations, or competitive position" (Genentech Inc, 2005). Also, pharmaceutical firms make an explicit commitment toward the environment, with Lifescan, Inc being a Charter Member of the EPA Performance Track which recognizes top environmental performance at US facilities (Lifescan, Inc, 2006). Johnson & Johnson's subsidiaries, which include Lifescan and Alza Corp, generally show this commitment, with Alza Corp's "Award-Winning, Innovative Sustainable Energy System". The cogeneration system at Alza is supplying electricity and heating water, while reducing carbon dioxide ($CO_2$) emissions by an average of 17.3 million pounds per year over the first ten years of the project. In 2005, Governor Arnold Schwarzenegger presented Johnson & Johnson's California family of companies with the Governor's Environmental and Economic Leadership Award, one of California's most prestigious environmental honors (Alza Corp, 2006).

Berkeley is the site of the global headquarters for the Hematology/Cardiology business unit of Bayer HealthCare Pharmaceuticals and the Bayer Diagnostics Molecular business. As a major employer in the Bay Area, Bayer HealthCare Pharmaceuticals has been recognized often for its efforts towards protecting the environment and promoting a diverse workforce. Bayer is a member of the American Chemistry Council and a full participant in the ACC's Responsible Care program, which promotes safe

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operation and open dialogue with the community (Bayer, 2006). Dunn-Edwards is also in support of the growing “green building” movement, which shares the philosophy of eco-efficiency (Dunn-Edwards, 2006).

Pfizer’s Global R&D, La Jolla Laboratories in Southern California is Pfizer's fastest growing R&D site, with potentially 1 million square feet of state-of-the-art lab and office space and over 1000 employees (Pfizer, 2003). Allergan has headquarters in Irvine, California, and is seeking to expand too (Allergan, Inc, 2006).

***Perspectives***

*Plant in Firm*

The scientific potential of biotechnology lends possibilities for expansion of facilities through increased-efficiency of production technology. Technological trends will depend on the industry’s execution of development roadmaps, and on the outcome of the design of next generation chemical plants. This has been outlined in the section above on Technology.

There is also a resurgence of interest in nuclear energy. In a future hydrogen production plant, a reactor may be connected by a long pipe to a chemical plant to produce hydrogen, using the reactor's heat to drive a thermochemical separation cycle. To produce hydrogen economically, a reactor must operate at extremely high temperatures. Thus the Very High Temperature Reactor has been selected for future hydrogen production plants. In the envisioned hydrogen economy, hydrogen will be used in fuel cells to propel automotive vehicles and power buildings. Because most hydrogen today is obtained from natural gas, producing significant greenhouse gases as a by-product, the Department of Energy plans to use nuclear reactors to produce hydrogen in an environmentally friendly fashion. DOE's Office of Nuclear Energy plans to build a VHTR, by 2015 or soon thereafter (Oakridge National Laboratory). This has implications for the inorganic chemicals sub-sector particularly, as it supplies hydrogen to refineries, and this is a significant source of emissions in the industry. The costs and gains in reducing power costs of the VHTR will have a bearing on firms’

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decisions regarding adjusting to the greenhouse gas reductions bills passed in California.

*Firm in industry*

"As a diverse and technologically advanced manufacturing sector, the chemical industry in California has significant opportunities to remain secure and viable in the future. Additionally, as demand for chemicals and pharmaceuticals grow globally, California's chemical industry stands poised to expand its markets and enhance growth" (California Energy Commission).

Three examples of successful firm competitiveness strategies (ARC Advisory Group, 2006):

<u>Pfizer</u>

The challenges faced by pharmaceutical manufacturers include compliance with regulatory issues, low cost sourcing, and managing an increasingly complex supply chain. In particular, Pfizer has confronted these challenges by automating processes that can be automated and integrating supply chain systems with plant floor systems with the overall strategy of getting the right information to the right people at the right time. To realize this goal, Pfizer encourages all of its automation suppliers to be compliant with industry standards, provide open connectivity to third party products and systems, and focus on business issues such as reduced cost of ownership. Pfizer also advised suppliers to stick to their key competencies. The industry also recognizes the need for integration between production management and control systems.

<u>Genentech</u>

Many of Genentech's reasons for implementing advanced automation were the same as Pfizer's, although Genentech added the element of safety, reduced time to market, an increasing degree of product changeovers, and implementation of improved production and maintenance scheduling. Another key element of Genentech's strategy behind integrating production management with control systems is the reduction of manufacturing complexity.

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Sterling Chemicals

Sterling Chemicals' strategy is to be a quality leader and in the top quartile as a low cost leader in supplying intermediate chemicals such as styrene, acetic acid, and plasticizers. Using the supplier's technology and services, Sterling Chemicals has been able to reduce the cost of compliance related to emission monitoring, exploit the reduction of process variability to produce higher product quality consistency and reduce operating cost, and extend lifetime of catalyst. Key success factors to the collaboration were the agreement on common goals, commitment to operational performance criteria that can be sustained, mutual benefit, and recognition of key benefits by the executive sponsor.

These case studies attest to the prominence of the pharmaceutical and inorganic chemicals sub-sectors they represent in California's chemicals industry, and show that firms do seek to improve operations in terms of energy reduction, and this may be due to their revenue outweighing the costs of doing so, or the unlikelihood of relocating due to regulatory requirements.

*Firm in state*

There are several roadmaps that serve as guidelines for firms, and also alliances of firms. For the former, the U.S. Department of Energy (DOE) Office of Industrial Technologies (OIT) established the Industries of the Future (IOF) program to increase energy efficiency, reduce waste production and to improve competitiveness, currently focusing on nine sectors. The California Energy Commission (CEC) is leading the State IOF program in California, as part of many other programs to improve the energy efficiency and performance of industries in California. In California the IOF effort focuses on petroleum refining, chemical processing, food processing and electronics. As part of this effort, the SIOF program will develop roadmaps for technology development for the selected sectors. On the basis of the roadmap, the program will develop successful projects with co-funding from state and federal government, and promote industry-specific energy-efficiency (US DOE-STI, 2004).

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For the latter, there exist alliances of firms such as ChemAlliance, and Technology Vision 2020. The goals to reach Vision 2020 include improving operations, with a focus on better management of the supply chain; improving efficiency in the use of raw materials, the reuse of recycled materials, and the generation and use of energy; continuing to play a leadership role in balancing environmental and economic considerations; aggressively committing to longer term investment in R&D; balancing investments in technology by leveraging the capabilities of government, academe, and the chemical industry as a whole through targeted collaborative efforts in R&D (Council for Chemical Research, 1999).

Possible conflicts of interest may arise due to the need to comply with new regulations with respect to the new bills passed. This has been mentioned to be one of the challenges that firms face. However, based on structure of the chemical industry in California being less energy-intensive in terms of usage, and the low proportion of expenditure on the environment as part of total costs of firms in the dominant and growing pharmaceutical sub-sector, chemical producing firms in California may not find the new regulations impacting their balance sheets significantly. Past trends of purported commitment to the environment, and involvement in such related programs with state agencies, also make it easier for firms to adjust to work with the state toward following the new bills passed.

Genentech:
http://www.gene.com/gene/ir/financials/annualreports/2005/financials/11yearsummary.jsp

Johnson & Johnson (related to Lifescan, Inc, and Alza Corp):
http://www.jnj.com/investor/documents/archive/2005HistoricalReview.pdf

Bayer:
http://www.bayer.com/annualreport_2005_id0602/financial_statements/income.php
http://www.bayer.com/annualreport_2005_id0602/financial_statements/balance_sheets.php

Pfizer:
http://www.pfizer.com/pfizer/annualreport/2005/financial/financial2005.pdf (pg 35)

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Allergan:
http://www.shareholder.com/AGN/EdgarDetail.cfm?CompanyID=AGN&CIK=850693&FID=892569-06-217&SID=06-00#A17071E10VK_HTM_303 (pg F-5)

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# ANNEX 1 - OVERVIEW OF THE BEAR MODEL

The Berkeley Energy and Resources (BEAR) model is in reality a constellation of research tools designed to elucidate economy-environment linkages in California. The schematics in Figures 2.1 and 2.2 describe the four generic components of the modeling facility and their interactions. This section provides a brief summary of the formal structure of the BEAR model.[34] For the purposes of this report, the 2003 California Social Accounting Matrix (SAM), was aggregated along certain dimensions. The current version of the model includes 50 sectors aggregated from the original California SAM. The equations of the model are completely documented elsewhere (Roland-Holst:2005), and for the present we only discuss its salient structural components.

## Structure of the CGE Model

Technically, a CGE model is a system of simultaneous equations that simulate price-directed interactions between firms and households in commodity and factor markets. The role of government, capital markets, and other trading partners are also specified, with varying degrees of detail and passivity, to close the model and account for economywide resource allocation, production, and income determination.

The role of markets is to mediate exchange, usually with a flexible system of prices, the most important endogenous variables in a typical CGE model. As in a real market economy, commodity and factor price changes induce changes in the level and composition of supply and demand, production and income, and the remaining endogenous variables in the system. In CGE models, an equation

[34] See Roland-Holst (2005) for a complete model description.

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system is solved for prices that correspond to equilibrium in markets and satisfy the accounting identities governing economic behavior. If such a system is precisely specified, equilibrium always exists and such a consistent model can be calibrated to a base period data set. The resulting calibrated general equilibrium model is then used to simulate the economywide (and regional) effects of alternative policies or external events.

The distinguishing feature of a general equilibrium model, applied or theoretical, is its closed-form specification of all activities in the economic system under study. This can be contrasted with more traditional partial equilibrium analysis, where linkages to other domestic markets and agents are deliberately excluded from consideration. A large and growing body of evidence suggests that indirect effects (e.g., upstream and downstream production linkages) arising from policy changes are not only substantial, but may in some cases even outweigh direct effects. Only a model that consistently specifies economywide interactions can fully assess the implications of economic policies or business strategies. In a multi-country model like the one used in this study, indirect effects include the trade linkages between countries and regions which themselves can have policy implications.

The model we use for this work has been constructed according to generally accepted specification standards, implemented in the GAMS programming language, and calibrated to the new California SAM estimated for the year 2003.[35] The result is a single economy model calibrated over the fifteen-year time path from 2005 to 2020.[36] Using the very detailed accounts of the California SAM, we include the following in the present model:

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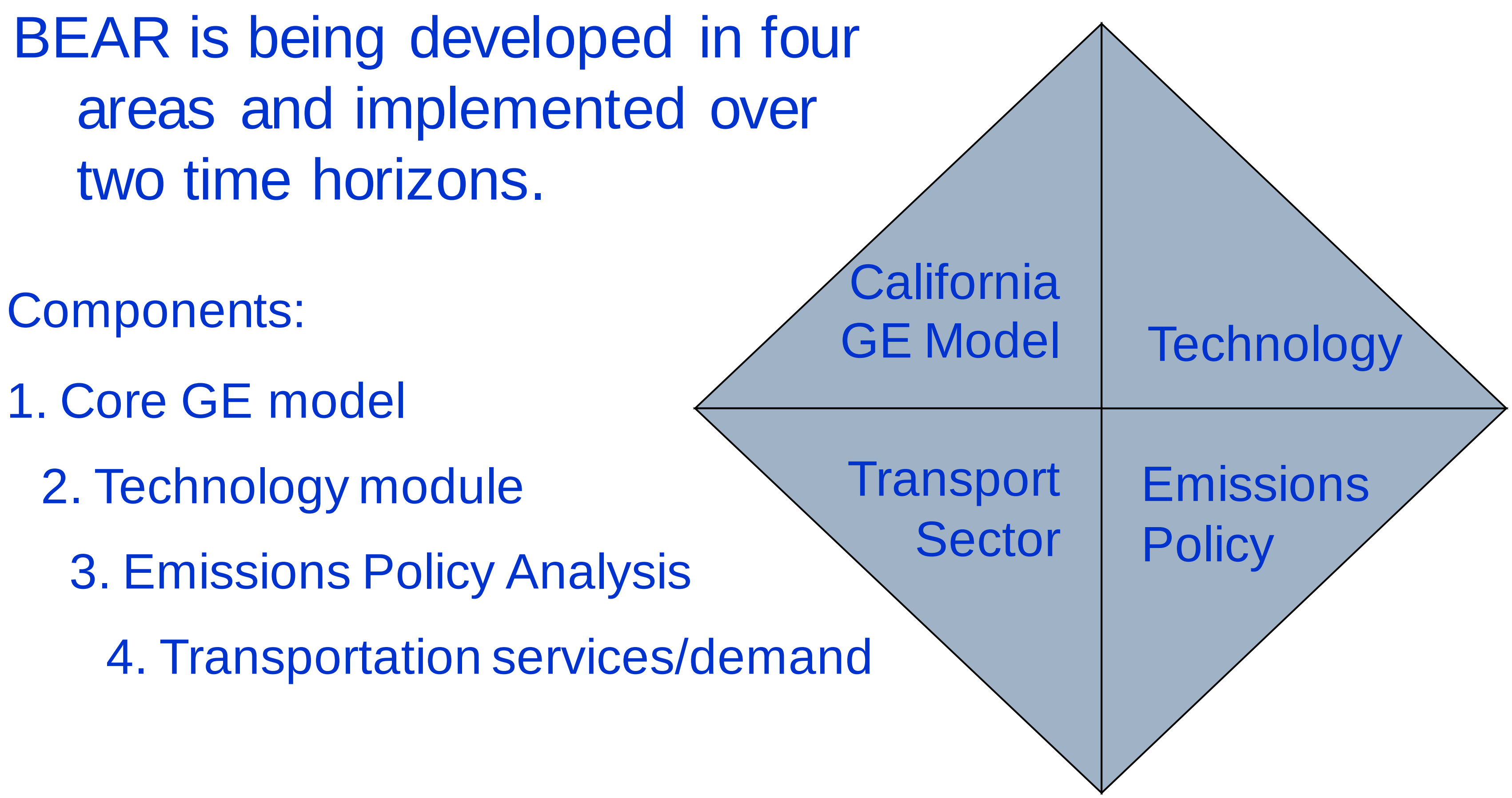
[35] See e.g. Meeraus et al (1992) for GAMS Berck et al (2004) for the California SAM.

[36] The present specification is one of the most advanced examples of this empirical method, already applied to over 50 individual countries or combinations thereof (see e.g. Francois and Roland-Holst, 2000; Lee and Roland-Holst, 1995, 2000, 1998ab; Lee et al., 1999).

**Figure 2.1: Component Structure of the Modeling Facility**



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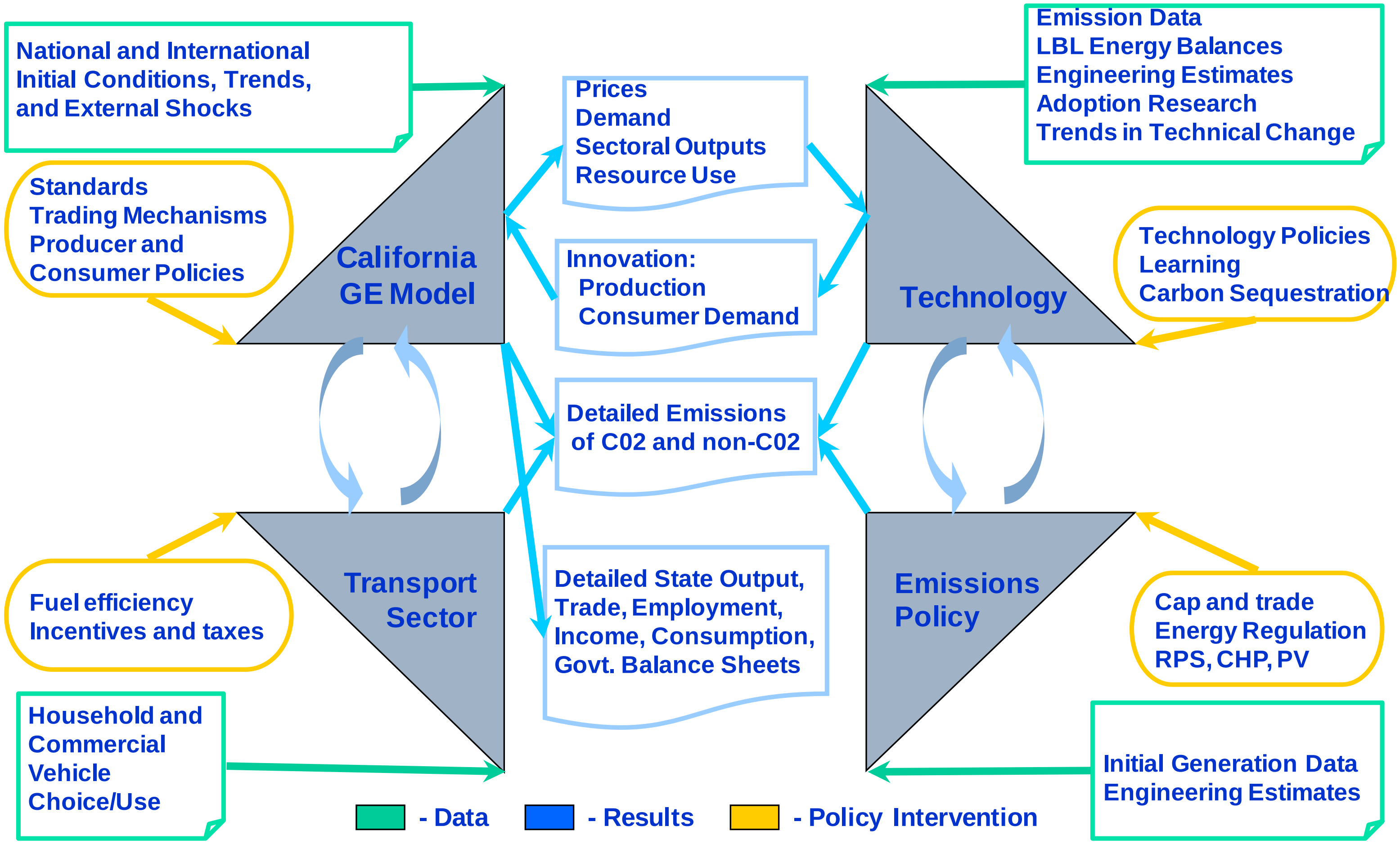
## Figure 2.2: Schematic Linkage between Model Components



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### Production

All sectors are assumed to operate under constant returns to scale and cost optimization. Production technology is modeled by a nesting of constant-elasticity-of-substitution (CES) functions. See Figure A1.1 for a schematic diagram of the nesting.

In each period, the supply of **primary** factors — capital, land, and labor — is usually predetermined.[37] The model includes adjustment rigidities. An important feature is the distinction between old and new capital goods. In addition, capital is assumed to be partially mobile, reflecting differences in the marketability of capital goods across sectors.[38]

Once the optimal combination of inputs is determined, sectoral output prices are calculated assuming competitive supply (zero-profit) conditions in all markets.

### Consumption and Closure Rule

All income generated by economic activity is assumed to be distributed to consumers. Each representative consumer allocates optimally his/her disposable income among the different commodities and saving. The consumption/saving decision is completely static: saving is treated as a "good" and its amount is determined simultaneously with the demand for the other commodities, the price of saving being set arbitrarily equal to the average price of consumer goods.

The government collects income taxes, indirect taxes on intermediate inputs, outputs and consumer expenditures. The default closure of the model assumes

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[37] Capital supply is to some extent influenced by the current period's level of investment.

[38] For simplicity, it is assumed that old capital goods supplied in second-hand markets and new capital goods are homogeneous. This formulation makes it possible to introduce downward rigidities in the adjustment of capital without increasing excessively the number of equilibrium prices to be determined by the model.

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that the government deficit/saving is exogenously specified.[39] The indirect tax schedule will shift to accommodate any changes in the balance between government revenues and government expenditures.

The current account surplus (deficit) is fixed in nominal terms. The counterpart of this imbalance is a net outflow (inflow) of capital, which is subtracted (added to) the domestic flow of saving. In each period, the model equates gross investment to net saving (equal to the sum of saving by households, the net budget position of the government and foreign capital inflows). This particular closure rule implies that investment is driven by saving.

### Trade

Goods are assumed to be differentiated by region of origin. In other words, goods classified in the same sector are different according to whether they are produced domestically or imported. This assumption is frequently known as the *Armington* assumption. The degree of substitutability, as well as the import penetration shares are allowed to vary across commodities. The model assumes a single Armington agent. This strong assumption implies that the propensity to import and the degree of substitutability between domestic and imported goods is uniform across economic agents. This assumption reduces tremendously the dimensionality of the model. In many cases this assumption is imposed by the data. A symmetric assumption is made on the export side where domestic producers are assumed to differentiate the domestic market and the export market. This is modeled using a *Constant-Elasticity-of-Transformation* (CET) function.

### Dynamic Features and Calibration

The current version of the model has a simple recursive dynamic structure as agents are assumed to be myopic and to base their decisions on static expectations about prices and quantities. Dynamics in the model originate in

[39] In the reference simulation, the real government fiscal balance converges (linearly) towards 0 by the final period of the simulation.

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three sources: i) accumulation of productive capital and labor growth; ii) shifts in production technology; and iii) the putty/semi-putty specification of technology.

### Capital accumulation

In the aggregate, the basic capital accumulation function equates the current capital stock to the depreciated stock inherited from the previous period plus gross investment. However, at the sectoral level, the specific accumulation functions may differ because the demand for (old and new) capital can be less than the depreciated stock of old capital. In this case, the sector contracts over time by releasing old capital goods. Consequently, in each period, the new capital vintage available to expanding industries is equal to the sum of disinvested capital in contracting industries plus total saving generated by the economy, consistent with the closure rule of the model.

### The putty/semi-putty specification

The substitution possibilities among production factors are assumed to be higher with the new than the old capital vintages — technology has a putty/semi-putty specification. Hence, when a shock to relative prices occurs (e.g. the imposition of an emissions fee), the demands for production factors adjust gradually to the long-run optimum because the substitution effects are delayed over time. The adjustment path depends on the values of the short-run elasticities of substitution and the replacement rate of capital. As the latter determines the pace at which new vintages are installed, the larger is the volume of new investment, the greater the possibility to achieve the long-run total amount of substitution among production factors.

### Dynamic calibration

The model is calibrated on exogenous growth rates of population, labor force, and GDP. In the so-called Baseline scenario, the dynamics are calibrated in each region by imposing the assumption of a balanced growth path. This implies that the ratio between labor and capital (in efficiency units) is held

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constant over time.[40] When alternative scenarios around the baseline are simulated, the technical efficiency parameter is held constant, and the growth of capital is endogenously determined by the saving/investment relation.

## Modelling Emissions

The BEAR model captures emissions from production activities in agriculture, industry, and services, as well as in final demand and use of final goods (e.g. appliances and autos). This is done by calibrating emission functions to each of these activities that vary depending upon the emission intensity of the inputs used for the activity in question. We model both CO2 and the other primary greenhouse gases, which are converted to CO2 equivalent. Following standards set in the research literature, emissions in production are modeled as factors inputs. The base version of the model does not have a full representation of emission reduction or abatement. Emissions abatement occurs by substituting additional labor or capital for emissions when an emissions tax is applied. This is an accepted modeling practice, although in specific instances it may either understate or overstate actual emissions reduction potential.[41] In this framework, mission levels have an underlying monotone relationship with production levels, but can be reduced by increasing use of other, productive factors such as capital and labor. The latter represent investments in lower intensity technologies, process cleaning activities, etc. An overall calibration procedure fits observed intensity levels to baseline activity and other factor/resource use levels. In some of the policy simulations we evaluate sectoral emission reduction scenarios, using specific cost and emission reduction factors, based on our earlier analysis (Hanemann and Farrell: 2006).

The model has the capacity to track 13 categories of individual pollutants and consolidated emission indexes, each of which is listed in Table 2.1 below. Our

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[40]This involves computing in each period a measure of Harrod-neutral technical progress in the capital-labor bundle as a residual. This is a standard calibration procedure in dynamic CGE modeling.

[41] See e.g. Babiker et al (2001) for details on a standard implementation of this approach.

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focus in the current study is the emission of $CO_2$ and other greenhouse gases, but the other effluents are of relevance to a variety of environmental policy issues. For more detail, please consult the full model documentation.

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**Table 2.1: Emission Categories**

| | | |
|---|---|---|
| *Air Pollutants* | | |
| 1. | Suspended particulates | PART |
| 2. | Sulfur dioxide ($SO_2$) | SO2 |
| 3. | Nitrogen dioxide ($NO_2$) | NO2 |
| 4. | Volatile organic compounds | VOC |
| 5. | Carbon monoxide (CO) | CO |
| 6. | Toxic air index | TOXAIR |
| 7. | Biological air index | BIOAIR |
| *Water Pollutants* | | |
| 8. | Biochemical oxygen demand | BOD |
| 9. | Total suspended solids | TSS |
| 10. | Toxic water index | TOXWAT |
| 11. | Biological water index | BIOWAT |
| *Land Pollutants* | | |
| 12. | Toxic land index | TOXSOL |
| 13. | Biological land index | BIOSOL |

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# ANNEX 2 – CEMENT INDUSTRY SUPPLEMENTAL DATA

**Table A3.1: Industry Statistics for Selected States, 2002**

## Table 2. Industry Statistics for Selected States: 2002

[States that are a disclosure or with less than 100 employees are not shown. Data based on the 2002 Economic Census. For information on confidentiality protection, nonsampling error, explanation of terms, and geographical definitions, see note at end of table. For information on geographic areas followed by *, see Appendix D. For meaning of abbreviations and symbols, see introductory text]

| Industry and geographic area | E[1] | All establishments[2] | | All employees | | Production workers | | | Value added ($1,000) | Total cost of materials ($1,000) | Total value of shipments ($1,000) | Total capital expenditures ($1,000) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Total | With 20 employees or more | Number[3] | Payroll ($1,000) | Number[3] | Hours (1,000) | Wages ($1,000) | | | | |
| **327310, Cement manufacturing** | | | | | | | | | | | | |
| United States | 2 | 246 | 148 | 17 854 | 902 085 | 13 308 | 28 649 | 620 865 | 4 569 418 | 2 949 444 | 7 454 784 | r1 368 108 |
| California | 3 | 25 | 17 | 2 039 | 111 120 | 1 517 | 3 475 | 77 451 | 586 308 | 422 896 | 1 005 094 | r44 054 |
| Florida | 4 | 12 | 8 | 889 | 42 872 | 680 | 1 466 | 30 144 | 229 579 | 155 773 | 389 265 | r32 792 |
| Illinois | 3 | 13 | 6 | 686 | 31 215 | 489 | 1 027 | 18 798 | 152 106 | 128 536 | 280 000 | r15 461 |
| Indiana | – | 5 | 4 | 626 | 30 067 | 481 | 1 026 | 21 237 | 197 156 | 91 285 | 286 515 | r28 542 |
| Iowa | – | 7 | 3 | 465 | 21 488 | 361 | 721 | 15 338 | 142 131 | 73 656 | 210 575 | r14 308 |
| Kansas | 3 | 5 | 4 | 549 | 25 642 | 412 | 852 | 17 107 | 110 944 | 64 456 | 176 152 | 16 444 |
| Michigan | 4 | 9 | 7 | 966 | 53 652 | 742 | 1 618 | 38 357 | 256 469 | 185 921 | 439 644 | r9 455 |
| Missouri | 2 | 10 | 6 | 947 | 45 087 | 731 | 1 381 | 32 978 | 299 510 | 132 749 | 428 071 | 13 508 |
| New York | – | 11 | 5 | 581 | 29 534 | 414 | 866 | 19 588 | 165 924 | 79 881 | 238 620 | r17 413 |
| Ohio | 5 | 12 | 3 | 340 | 17 868 | 247 | 538 | 12 300 | 79 778 | 46 345 | 129 323 | r3 619 |
| Oklahoma | – | 4 | 3 | 376 | 18 599 | 276 | 554 | 9 777 | 93 763 | 35 865 | 126 791 | r3 561 |
| Pennsylvania | 1 | 20 | 15 | 1 666 | 83 433 | 1 258 | 2 628 | 57 756 | 386 484 | 212 532 | 585 768 | r47 242 |
| Tennessee | – | 7 | 2 | 242 | 12 585 | 194 | 408 | 9 373 | 97 178 | 34 424 | 127 576 | r2 021 |
| Texas | 1 | 17 | 15 | 1 730 | 82 662 | 1 296 | 2 901 | 57 764 | 546 427 | 337 585 | 877 845 | r39 367 |

[1]Some payroll and sales data for small single-establishment companies with up to 20 employees (cutoff varied by industry) were obtained from administrative records of other government agencies rather than from census report forms. These data were then used in conjunction with industry averages to estimate statistics for these small establishments. This technique was also used for a small number of other establishments whose reports were not received at the time data were tabulated. The following symbols are shown where estimated data account for 10 percent or more of the figures shown: 1–10 to 19 percent; 2–20 to 29 percent; 3–30 to 39 percent; 4–40 to 49 percent; 5–50 to 59 percent; 6–60 to 69 percent; 7–70 to 79 percent; 8–80 to 89 percent; 9–90 percent or more.

[2]Includes establishments with payroll at any time during the year.

[3]Number of employees figures represent average number of production workers for pay period that includes the 12th of March, May, August, and November plus other employees for payroll period that includes the 12th of March.

Note: The data in this table are based on the 2002 Economic Census. To maintain confidentiality, the Census Bureau suppresses data to protect the identity of any business or individual. The census results in this table contain nonsampling errors. Data users who create their own estimates using data from American FactFinder tables should cite the Census Bureau as the source of the original data only. For explanation of terms, see Appendix A. For full technical documentation, see Appendix C. For geographical definitions, see Appendix D.

(U.S.…,Bureau 2002)

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## Tables A3.2-3.3: Kiln Data Summary By Process Type; Kiln Data Summary By Hazardous Waste Burning Status

TABLE 2-3. KILN DATA SUMMARY BY PROCESS TYPE: 1995

| Process type | Number of kilns | Clinker capacity ($10^3$ short tpy) Total | Clinker capacity ($10^3$ short tpy) Average per kiln | Net CKD generation ($10^3$ short tpy) | Average kiln age (years) | Operation cost[a] ($/short ton) |
|---|---|---|---|---|---|---|
| Wet | 69 | 22,802 | 330 | 2,257 | 31.7 | $36.92 |
| Dry | 134 | 60,949 | 455 | 1,399 | 20.5 | $33.90 |
| Dry-without PH/PC | 67 | 17,936 | 268 | 786 | 31.2 | $38.98 |
| Dry-preheater | 39 | 17,537 | 450 | 253 | 20.5 | $33.75 |
| Dry-precalciner | 28 | 25,476 | 910 | 361 | 13.3 | $30.56 |
| All kilns | 203 | 83,751 | 413 | 3,656 | 23.5 | $34.72 |

[a] Estimation of operating cost per ton is detailed in Appendix C.

TABLE 2-4. KILN DATA SUMMARY BY HAZARDOUS WASTE BURNING STATUS: 1995

| Status | Number of kilns | Clinker capacity ($10^3$ short tpy) Total | Clinker capacity ($10^3$ short tpy) Average per kiln | Net CKD generation ($10^3$ short tpy) | Average kiln age (years) | Operation cost[a] ($/short ton) |
|---|---|---|---|---|---|---|
| Burning hazardous waste | 38 | 13,871 | 365 | 1,553 | 26.5 | $33.35 |
| Not burning hazardous waste | 165 | 69,880 | 424 | 2,103 | 22.9 | $34.99 |
| All kilns | 203 | 83,751 | 413 | 3,656 | 23.5 | $34.72 |

[a] Estimation of operating cost per ton is detailed in Appendix C.

(Regulatory…Rulemaking, 1998)

## Table A3.4: Portland Cement Shipped By Producers and Importers In the United States By District

TABLE 11

PORTLAND CEMENT SHIPPED BY PRODUCERS AND IMPORTERS IN THE UNITED STATES, BY DISTRICT[1]

| | 2003 | | | 2004 | | |
|---|---|---|---|---|---|---|
| | | Value[2] | | | Value[2] | |
| District[3,4] | Quantity (thousand metric tons) | Total (thousands) | Average (dollars per metric ton) | Quantity (thousand metric tons) | Total (thousands) | Average (dollars per metric ton) |
| Maine and New York | 2,142 | $158,000 [5] | 74.00 [5] | 3,556 | $269,944 | 75.91 |
| Pennsylvania, eastern | 4,336 | 317,000 [5] | 73.00 [5] | 4,830 [5] | 363,000 [5] | 75.00 [5] |
| Pennsylvania, western | 1,404 | 106,000 [5] | 75.50 [5] | 1,535 | 120,000 [5] | 78.00 [5] |
| Illinois | 2,988 | 215,000 [5] | 72.00 [5] | 3,052 | 235,921 | 77.31 |
| Indiana | 2,830 [5] | 196,379 | 69.39 | 3,013 | 213,484 | 70.85 |
| Michigan and Wisconsin | 6,600 [5] | 490,000 [5] | 74.00 [5] | 6,611 | 535,000 [5] | 81.00 [5] |
| Ohio | 1,078 | 85,872 | 79.64 | 1,005 | 84,700 [5] | 84.00 [5] |
| Iowa, Nebraska, South Dakota | 4,869 | 378,034 | 77.65 | 4,802 | 394,319 | 82.12 |
| Kansas | 2,051 | 156,000 [5] | 76.00 [5] | 2,222 | 175,000 [5] | 79.00 [5] |
| Missouri | 6,291 | 426,931 | 68.87 | 6,058 | 446,008 | 73.63 |
| Florida | 8,289 | 638,000 [5] | 77.00 [5] | 9,430 [5] | 776,000 [5] | 82.50 [5] |
| Georgia, Virginia, West Virginia | 2,730 | 193,000 [5] | 70.50 [5] | 2,951 | 220,030 | 74.55 |
| Maryland | 2,483 | 165,935 | 66.82 | 2,733 | 189,628 | 69.38 |
| South Carolina | 3,210 | 198,000 [5] | 61.50 [5] | 3,491 | 220,162 | 63.06 |
| Alabama | 4,275 | 269,000 [5] | 63.00 [5] | 4,621 | 308,181 | 66.69 |
| Kentucky, Mississippi, Tennessee | 3,183 | 218,000 [5] | 68.50 [5] | 3,087 | 227,798 | 73.79 |
| Arkansas and Oklahoma | 2,797 | 196,459 | 70.24 | 2,658 | 198,487 | 74.68 |
| Texas, northern | 6,660 [5] | 449,000 [5] | 67.50 [5] | 7,678 | 559,000 [5] | 73.00 [5] |
| Texas, southern | 6,020 [5] | 408,030 | 67.78 | 6,270 [5] | 435,000 [5] | 69.50 [5] |
| Arizona and New Mexico | 3,676 | 342,180 | 93.08 | 3,969 | 368,314 | 92.80 |
| Colorado and Wyoming | 2,329 | 169,619 | 72.82 | 2,786 | 206,658 | 74.19 |
| Idaho, Montana, Nevada, Utah | 3,097 | 245,000 [5] | 79.00 [5] | 3,245 | 281,775 | 86.83 |
| Alaska and Hawaii | 454 | 58,952 | 129.80 | 499 | 64,680 | 129.53 |
| California, northern | 3,751 | 302,695 | 80.69 | 4,257 | 369,806 | 86.88 |
| California, southern | 9,881 | 740,801 | 74.97 | 10,764 | 881,243 | 81.87 |
| Oregon and Washington | 1,897 | 145,334 | 76.61 | 2,690 [5] | 207,000 [5] | 77.00 [5] |
| Independent importers, n.e.c.[6,7] | 7,140 [5] | 555,000 [5] | 78.00 [5] | 6,790 [5] | 598,000 [5] | 88.00 [5] |
| Total or average[8] | 106,000 [5,9] | 7,820,000 [5] | 73.50 [5] | 115,000 [5,9] | 8,950,000 [5] | 78.00 [5] |
| Puerto Rico | 1,848 | W | W | 1,868 | W | W |
| Grand total[8] | 108,000 [5,9] | W | W | 116,000 [5,9] | W | W |

W Withheld to avoid disclosing company proprietary data.

[1]Includes portland cement (gray and white) and cement produced from imported clinker. Even where presented unrounded, data are thought to be accurate to no more than three significant digits.

[2]Values represent mill net or ex-plant (free on board plant) valuations of total sales to final customers, including sales from plant distribution terminals. The data are ex-terminal for independent terminals. All varieties of portland cement, and both bag and bulk shipments, are included. Unless otherwise specified, data are presented unrounded but may include cases where value data (only) were missing from survey forms and so were estimated. Accordingly, unrounded value data should be viewed as cement value indicators, good to no better than the nearest $0.50 or even $1.00 per ton.

[3]District is the location of the reporting facility, not the location of sales.

[4]Includes shipments by independent importers where regional assignations were possible.

[5]Data are rounded (unit values to the nearest $0.50) because they include estimated data.

[6]Importers for which district assignations were not possible.

[7]Not elsewhere classified.

[8]Data may not add to totals shown because of independent rounding.

[9]Shipments calculated on the basis of an annual survey of plants and importers; may differ from data in table 9, which are based on consolidated company monthly data.

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**Table A3.5: Portland Cement Shipments in 2004 By District and Type of Customer**

TABLE 14

PORTLAND CEMENT SHIPMENTS IN 2004, BY DISTRICT AND TYPE OF CUSTOMER[1]

(Thousand metric tons)

| District[2, 3] | Ready-mixed concrete | Concrete product manufacturers[4] | Contractors[5] | Building material dealers | Oil well, mining, waste[6] | Government and miscellaneous[7] | Total[8, 9] |
|---|---|---|---|---|---|---|---|
| Maine and New York | 2,680 | 485 | 90 | 274 | -- | 31 | 3,556 |
| Pennsylvania, eastern | 3,050 | 1,270 | 164 | 250 | 2 | 91 | 4,830 |
| Pennsylvania, western | 1,080 | 259 | 157 | 5 | 16 | 16 | 1,535 |
| Illinois | 2,280 | 373 | 113 | 40 | 139 | 105 | 3,052 |
| Indiana | 2,300 | 436 | 182 | 73 | 10 | 16 | 3,013 |
| Michigan and Wisconsin | 5,110 | 770 | 371 | 182 | 18 | 163 | 6,611 |
| Ohio | 788 | 132 | 47 | 29 | 1 | 9 | 1,005 |
| Iowa, Nebraska, South Dakota | 3,660 | 589 | 358 | 74 | 108 | 9 | 4,802 |
| Kansas | 1,650 | 131 | 322 | 72 | 45 | 1 | 2,222 |
| Missouri | 4,850 | 418 | 662 | 99 | 7 | 22 | 6,058 |
| Florida | 6,750 | 1,920 | 123 | 632 | -- | 11 | 9,430 |
| Georgia, Virginia, West Virginia | 2,270 | 437 | 180 | 37 | 21 | 9 | 2,951 |
| Maryland | 1,950 | 462 | 167 | 52 | 5 | 96 | 2,733 |
| South Carolina | 2,250 | 701 | 312 | 140 | 1 | 87 | 3,491 |
| Alabama | 3,570 | 662 | 201 | 141 | 16 | 36 | 4,621 |
| Kentucky, Mississippi, Tennessee | 2,500 | 383 | 125 | 63 | 11 | 2 | 3,087 |
| Arkansas and Oklahoma | 1,790 | 132 | 565 | 105 | 61 | 8 | 2,658 |
| Texas, northern | 4,960 | 560 | 1,070 | 137 | 731 | 228 | 7,678 |
| Texas, southern | 4,240 | 611 | 729 | 204 | 455 | 32 | 6,270 |
| Arizona and New Mexico | 2,820 | 622 | 238 | 121 | 21 | 145 | 3,969 |
| Colorado and Wyoming | 2,170 | 314 | 179 | 55 | 65 | 5 | 2,786 |
| Idaho, Montana, Nevada, Utah | 2,590 | 238 | 116 | 40 | 228 | 38 | 3,245 |
| Alaska and Hawaii | 419 | 65 | 11 | 1 | -- | 4 | 499 |
| California, northern | 3,560 | 279 | 114 | 302 | -- | 4 | 4,257 |
| California, southern | 7,330 | 2,620 | 351 | 375 | 84 | 3 | 10,764 |
| Oregon and Washington | 1,960 | 390 | 178 | 114 | 41 | 3 | 2,690 |
| Independent importers, n.e.c.[10, 11] | 5,220 | 986 | 216 | 206 | 44 | 117 | 6,790 |
| Total[9] | 83,800 | 16,200 | 7,340 | 3,820 | 2,130 | 1,290 | 115,000 |
| Puerto Rico | 1,090 | 173 | 81 | 527 | -- | -- | 1,868 |
| Grand total[9] | 84,900 | 16,400 | 7,420 | 4,350 | 2,130 | 1,290 | 116,000 |

-- Zero.

[1]Includes imported cement and cement ground from imported clinker. Except for district totals, data have been rounded to three significant digits but are likely to be accurate to only two significant digits. District totals are accurate to no more than three significant digits.

[2]District location is that of the reporting facilities and may include sales by them into other districts.

[3]Includes shipments by independent importers for which district assignations were possible.

[4]Grand total shipments to concrete product manufacturers include brick and block—6,390; precast and prestressed—3,580; pipe—2,190; and other or unspecified—4,270.

[5]Grand total shipments to contractors include airport—164; road paving—4,170; soil cement—1,150; and other or unspecified—1,930.

[6]Grand total shipments include oil well drilling—1,800; mining—217; and waste stabilization—116.

[7]Includes shipments for which customer types were not specified.

[8]District totals are not rounded except in accord with the data in table 11.

[9]Data may not add to totals shown because of independent rounding.

[10]Shipments by independent importers for which district assignations were not possible.

[11]Not elsewhere classified.

Source: Van Oss, 2004

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**Table A3.6: PIER Emissions Estimates**

| Phase | Product | California GHG Emissions | |
|---|---|---|---|
| | | (Mt $CO_2$) | (MtC) |
| Production | Cement plant | 9.6 | 2.6 |
| | Other cement-related | 0.9 | 0.2 |
| | Total cement | 10.4 | 2.8 |
| | Concrete | 1.4 | 0.4 |
| | Total | 11.8 | 3.2 |
| Use | | 0.0 | 0.0 |
| End-of-Life | | 0.018 | 0.005 |
| **Total** | | 11.8 | 3.2 |

Source: PIER, 2005

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## Table A3.7: Energy Savings Opportunities

| Raw Materials Preparation | |
|---|---|
| Efficient transport systems (dry process)<br>Slurry blending and homogenization (wet process)<br>Raw meal blending systems (dry process)<br>Conversion to closed circuit wash mill (wet process)<br>High-efficiency roller mills (dry cement)<br>High-efficiency classifiers (dry cement)<br>Fuel preparation: Roller mills | |
| **Clinker Production (Wet)** | **Clinker Production (Dry)** |
| Energy management and process control<br>Seal replacement<br>Kiln combustion system improvements<br>Kiln shell heat loss reduction<br>Use of waste fuels<br>Conversion to modern grate cooler<br>Refractories<br>Optimize grate coolers<br>Conversion to pre-heater, pre-calciner kilns<br>Conversion to semi-dry kiln (slurry drier)<br>Conversion to semi-wet kiln<br>Efficient kiln drives<br>Oxygen enrichment | Energy management and process control<br>Seal replacement<br>Kiln combustion system improvements<br>Kiln shell heat loss reduction<br>Use of waste fuels<br>Conversion to modern grate cooler<br>Refractories<br>Heat recovery for power generation<br>Low pressure drop cyclones<br>Optimize grate coolers<br>Addition of pre-calciner to pre-heater kiln<br>Conversion to multi-stage pre-heater kiln<br>Efficient kiln drives<br>Oxygen enrichment |
| **Finish Grinding** | |
| Energy management and process control<br>Improved grinding media (ball mills)<br>High-pressure roller press<br>High efficiency classifiers | |
| **General Measures** | |
| Preventative maintenance (insulation, compressed air system, maintenance)<br>High efficiency motors<br>Efficient fans with variable speed drives<br>Optimization of compressed air systems<br>Efficient lighting | |

Source: Worrell and Galitsky (2004)

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