6. COST-EFFECTIVENESS OF ZEVS AND PARTIAL ZERO EMISSION VEHICLES

We begin this section by combining the cost estimates in Section 4 with the emission reductions in Section 5 to predict the cost-effectiveness of technologies that manufacturers may use to meet ZEV program requirements. Cost-effectiveness is measured as the cost per ton of non-methane organic gases (NMOG) plus oxides of nitrogen (NOx) emissions reduced. We then compare these estimates with the cost-effectiveness of other measures that have recently been adopted or are scheduled to be adopted to reduce emissions of ozone precursors in the South Coast. Finally, since cost-effectiveness calculations rarely cover all considerations that should be taken into account when developing policies and programs, we examine potential costs and benefits of California’s ZEV program that are not reflected in our cost-effectiveness estimates.

6.1 COST-EFFECTIVENESS ESTIMATES

We first calculate the cost-effectiveness of the various advanced vehicle technologies in the near term. For battery-powered electric vehicles (BPEVs), advanced technology partial zero emission electric vehicles (ATPZEVs), and partial zero emission vehicles (PZEVs), this period is 2003 through 2007. For direct hydrogen fuel-cell vehicles (DHFCVs), it is 2006 through 2010, because we think it unlikely that fuel-cell vehicles will be ready for the market in more than pilot quantities before then (see Subsection 3.1). We then project cost-effectiveness when the vehicles are in volume production.

The low costs in volume production can be thought of as the payoff society can expect after incurring high costs when a new technology is introduced. But in evaluating whether an investment makes sense, society must consider not only the payoff, but also the costs of achieving it. Thus, we also calculate cost-effectiveness for each technology that includes the higher costs of vehicles produced prior to volume production.

We calculate the cost-effectiveness of moving to progressively tighter emission control standards. We first calculate the cost-effectiveness of a PZEV relative to a vehicle that meets the super ultra low emission vehicle (SULEV) exhaust and the near-zero evaporative standards. Then we calculate the cost-effectiveness of ATPZEVs, which in this case are gasoline hybrid electric vehicles (GHEVs), and ZEVs relative to PZEVs. This allows us to evaluate whether the PZEV standard is sensible on cost-effectiveness grounds and, in turn, whether it makes sense to further reduce vehicle emissions.

Our estimates of cost-effectiveness implicitly assume that consumers are willing to pay the same amount, on a lifecycle basis, for the vehicles being compared. It assumes, for example, that
consumers value a full-function electric vehicle (EV) with a 100-mile range just as much as they value a comparably sized internal combustion engine vehicle (ICEV) with the same lifecycle cost. Consumers may be willing to pay more for a full-function EV if they view the benefits of a quiet ride, home recharging, and low emissions as outweighing the drawbacks of limited range. If they are willing to pay more, then this part of the higher full-function EV cost should not be included in the cost-effectiveness calculation. But consumer willingness to pay more for EVs is a subject of great debate. Appendix E reviews studies of the market for EVs. Based on our review, we think it reasonable to compare vehicles with the characteristics specified here based on their lifecycle costs.

Cost-Effectiveness in Near-Term and in Volume Production

To calculate cost-effectiveness for vehicles produced between 2003 and 2007, we divide the 90 percent probability intervals for discounted incremental lifecycle cost by the emission reductions generated over the lifetime of the vehicle. The result is cost per ton of emissions reduced, or the cost-effectiveness ratio. The higher the cost per ton, the less cost-effective the technology. Emissions are discounted back to the time of the vehicle sale. Discounted incremental lifecycle costs are taken from the analysis described in Subsection 4.4; they include the incremental costs of producing the vehicle and the incremental operating and maintenance costs over the life of the vehicle discounted back to the time of production. We assume that vehicle mileage (and thus emission reductions) is spread evenly over the vehicle’s lifetime. All vehicles except city EVs are assumed to travel 10,000 miles per year for 15 years. City EVs are assumed to travel 5,000 miles per year for 15 years. As with costs, emission reductions are discounted back to the time of vehicle production using a 4 percent discount rate.1

Cost per ton in volume production is calculated in the same manner. The discounted emission reductions are identical to those for vehicles sold between 2003 and 2007. The discounted incremental lifecycle costs are taken from Table 4.17 (see Subsection 4.7).

Table 6.1 reports the results of the analysis. The brackets in each cell contain the interval into which cost per ton is likely to fall given our estimates of emission reduction and the 90 percent probability intervals for incremental lifecycle cost.2 For example, we predict that cost per ton for full-function EVs with NiMH batteries produced between 2003 and 2007 will be from $1.5 to $2.3 million per ton of NMOG plus NOx reduced. In volume production, the cost per ton

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1The discounting of emission benefits is controversial among noneconomists, but is standard in economic analysis.

2Because our emission reduction estimates are point estimates (constants), the intervals for cost per ton are still formally 90 percent probability intervals. Of course, there is uncertainty in the emission reduction estimates, but we have not attempted to characterize it in this analysis.


Table 6.1
Cost-Effectiveness Ratio of Vehicle Technologies in Near Term and in Volume Production (intervals in brackets; $1000s per ton of NMOG+NOx reduced)

<table>
<thead>
<tr>
<th>Vehicle Technology</th>
<th>Near Term</th>
<th>High-Volume Production</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2003-2007</td>
<td></td>
</tr>
<tr>
<td>PZEV relative to SULEV with</td>
<td>[18, 71]</td>
<td>[18, 71]</td>
</tr>
<tr>
<td>near-zero evap. emissions</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GHEV relative to PZEV</td>
<td>[650, 1,800]</td>
<td>[-500, 86]</td>
</tr>
<tr>
<td>Full-function EV relative to PZEV NiMH</td>
<td>[1,500, 2,300]</td>
<td>[260, 710]</td>
</tr>
<tr>
<td>PbA</td>
<td>[750, 1,500]</td>
<td>[12, 400]</td>
</tr>
<tr>
<td>City EV relative to PZEV NiMH</td>
<td>[1,400, 2,100]</td>
<td>[70, 370]</td>
</tr>
<tr>
<td>PbA</td>
<td>[850, 1,600]</td>
<td>[-80, 160]</td>
</tr>
<tr>
<td>DHFCV relative to PZEV</td>
<td>[650, 1,300]</td>
<td>[-110, 270]</td>
</tr>
<tr>
<td></td>
<td>2006-2010</td>
<td></td>
</tr>
</tbody>
</table>

of emissions reduced will likely still range from $260,000 to $710,000. These full-function EV costs and emission reductions are relative to those of a PZEV. We predict that relative to a SULEV with near-zero evaporative emission control, a PZEV will reduce emissions at a cost of $18,000 to $71,000 per ton.3

Cost-Effectiveness Including Transition Costs

To calculate cost-effectiveness for each technology that includes the costs and emission benefits of vehicles produced before costs fall to volume production levels, we specify production volumes and the decline in lifecycle cost over time. For the production volumes, we take the midpoint of the production scenarios we developed for each vehicle type in Subsection 3.2. Incremental lifecycle costs in 2003 are alternately set at the upper and lower bounds of the ranges for 2003 to 2007 reported in Table 4.17 and then fall to their high-volume levels by the dates shown in Table 6.2. For all vehicles except PZEVs, we selected these dates because our estimated cost-volume relationships (see Section 4) imply that annual production volumes will be high enough by these dates for costs to be approaching high-volume levels. For PZEVs, we assume that incremental costs remain unchanged from 2003 on. The decline in costs between 2003 and the year costs reach their high-volume levels for vehicles other than PZEVs reflects the decline in costs predicted by the cost-volume relationship.4 We discount both costs and emission

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3In some cases, the cost per ton is negative. This occurs when the discounted incremental cost is negative.

4In particular, we assume that the cumulative percent decline predicted by the cost-volume relationship between 2003 and the year costs reach their high-volume levels matches the cumulative percent decline in the costs used here between 2003 and the year costs reach their high-volume levels.
Table 6.2
Year in Which Incremental Lifecycle Costs Fall to High-Volume Predictions

<table>
<thead>
<tr>
<th>Vehicle Technology</th>
<th>Year High-Volume Cost Achieved</th>
</tr>
</thead>
<tbody>
<tr>
<td>GHEV</td>
<td>2015</td>
</tr>
<tr>
<td>Full-function EV</td>
<td></td>
</tr>
<tr>
<td>NiMH</td>
<td>2015</td>
</tr>
<tr>
<td>PbA</td>
<td>2015</td>
</tr>
<tr>
<td>City EV</td>
<td></td>
</tr>
<tr>
<td>NiMH</td>
<td>2015</td>
</tr>
<tr>
<td>PbA</td>
<td>2015</td>
</tr>
<tr>
<td>DHFCV</td>
<td>2020</td>
</tr>
</tbody>
</table>

reductions back to 2002, and we run the simulation out to the year 2100. We chose 2100 because at a 4 percent discount rate, discounted costs and emission reductions beyond 2100 are not large (in 2100, costs and emission reductions are multiplied by 0.021 to bring them back to 2002). Production volumes are fixed at their 2030 levels (the last year projected in Subsection 3.2) through 2100.

Table 6.3 reports the effect of including transition costs in the calculation of cost-effectiveness. The brackets contain the lower and upper bounds of our estimates. The second and third columns show the total discounted costs and discounted emission reductions for the assumed volume scenario. The last column reports cost per ton of NMOG plus NOx reduced in current dollars. As expected, the cost-effectiveness ratio is higher when transition costs are included than when only high-volume costs are considered. For example, cost per ton ranges from $12,000 to $400,000 per ton in Table 6.1 for a full-function EV with PbA batteries in volume production. When we include the costs incurred before costs fall to their high-volume levels, however, cost per ton rises to $50,000 to $470,000 per ton. The resource costs generated under these different scenarios are large. Discounted incremental costs of full-function EVs with NiMH batteries add up to $5.3 to $13.1 billion, yet the vehicles generate only 16,000 tons of discounted emission reductions.

6.2 COST-EFFECTIVENESS OF ADVANCED VEHICLE TECHNOLOGIES IN PERSPECTIVE

Subsection 2.4 reviews the cost-effectiveness of measures recently adopted or being considered to reduce NMOG and NOx emissions in the South Coast Air Basin. We found that regulations to reduce NMOG emissions from consumer products have cost up to $7,000 per ton.

5Even though based on the 90 percent probability intervals, these ranges are, strictly speaking, no longer 90 percent probability intervals.
Table 6.3  
Cost-Effectiveness Ratio of Vehicle Technologies Including Transition Costs (ranges in brackets)

<table>
<thead>
<tr>
<th>Vehicle Technology</th>
<th>Discounted Costs ($millions)</th>
<th>Discounted Emission Reductions (1000s of tons NMOG+NOx)</th>
<th>Cost per Ton ($1000 per ton NMOG+NOx reduced)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PZEV relative to SULEV with</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>near-zero evap. emissions</td>
<td>[850, 3,300]</td>
<td>47</td>
<td>[18, 71]</td>
</tr>
<tr>
<td>GHEV relative to PZEV</td>
<td>[-1,500, 600]</td>
<td>3</td>
<td>[-440, 180]</td>
</tr>
<tr>
<td>Full-function EV relative to PZEV</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NiMH</td>
<td>[5,300, 13,100]</td>
<td>16</td>
<td>[330, 810]</td>
</tr>
<tr>
<td>PbA</td>
<td>[870, 7,700]</td>
<td>16</td>
<td>[50, 470]</td>
</tr>
<tr>
<td>City EV relative to PZEV</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NiMH</td>
<td>[1,200, 3,800]</td>
<td>8</td>
<td>[150, 470]</td>
</tr>
<tr>
<td>PbA</td>
<td>[-200, 2,000]</td>
<td>8</td>
<td>[-20, 250]</td>
</tr>
<tr>
<td>DHFCV relative to PZEV(^a)</td>
<td>[-1,300, 5,000]</td>
<td>16</td>
<td>[-80, 310]</td>
</tr>
</tbody>
</table>

\(^a\)Year 2006 and on, only.

reduced and that regulations to reduce NMOG emissions from other stationary sources are expected to cost up to $25,000 per ton. Regulations on diesel engines target mainly NOx emissions and have been inexpensive on a cost-per-ton basis—all $800 per ton or less. Further regulation of gasoline engines is more expensive. Estimates of reducing light-duty vehicle (LDV) emissions by scrapping old vehicles or through the enhanced Smog Check program run up to $33,000 per ton of NMOG plus NOx reduced, and regulation of large and small off-road gasoline engines reaches nearly $21,000 per ton.

While these estimates are sometimes higher than the guidelines that the South Coast Air Quality Management District (SCAQMD) and CARB have set to evaluate the cost-effectiveness of proposed regulations,\(^6\) they are at least comparable to dollar estimates of the benefits of reducing NMOG and NOx emissions. In their review of the literature, Dixon and Garber (1996, pp. 21-22, 364-370) conclude that the benefits of reducing NMOG and NOx emissions in the South Coast likely exceed $5,000 per ton, perhaps by a substantial amount, but are probably less than $25,000 per ton.\(^7\) (These figures, which are in 1995 dollars, rise to $5,800 and $29,000 when converted to 2001 dollars.\(^8\))

\(^6\)Cost-effectiveness greater than $13,500 per ton of NMOG triggers further review at SCAQMD. CARB guidance sets an upper limit of $22,000 per ton of NMOG plus NOx (see Subsection 2.4).
\(^7\)The studies vary by the extent to which they include chronic versus acute human health effects, damage to plants and animals, and damage to materials. The range in benefit estimates is in part due to this variation.
\(^8\)Conversion done using the consumer price index. See [http://data.bls.gov/cgi-bin/surveymost](http://data.bls.gov/cgi-bin/surveymost).
On a cost-per-ton basis, PZEVs appear to be an attractive way to reduce NMOG and NOx emissions. The low end of our predicted range ($18,000) is comparable to the costs of many recently adopted regulations per ton. The upper end of the range ($71,000) is substantially higher than the cost of recently adopted regulations. However, it seems at least plausible that cost per ton will have to rise to such a level if emission reduction targets are to be met in the South Coast. The cost-effectiveness estimates for PZEVs are based on the costs of converting passenger cars and the smallest light-duty trucks (CARB’s LDT1 category) to PZEVs. Costs of converting the heavier pickups, sport utility vehicles (SUVs), and minivans common on the road today (CARB’s LDT2 category) to PZEVs may be higher.

Moving from PZEVs to GHEVs may or may not be a sensible way to reduce ozone levels. When GHEV maintenance costs are comparable to those of ICEVs, the cost per ton of emissions reduced is low or even negative. However, if the battery must be replaced during the life of the vehicle, the cost per ton is not particularly attractive, especially when transition costs are included. Because the difference between PZEV and GHEV emissions is small, cost per ton is very sensitive to changes in the incremental cost of GHEVs. GHEV incremental cost must therefore be small if cost per ton is to be moderate.

The cost per ton of moving from PZEVs to full-function EVs with NiMH batteries is huge. Even in volume production, the estimates run from $260,000 to $710,000 per ton of NMOG plus NOx reduced. Full-function EVs with PbA batteries look more attractive, but once transition costs are included, the cost is still $50,000 to $470,000 per ton (see Table 6.3). What is more, there are real doubts about whether it is practicable to produce full-function EVs with a 100-mile range and broad appeal using PbA batteries.

The high cost-effectiveness ratio reflects the small emission difference between PZEVs and BPEVs. The lower end of our range for the incremental high-volume cost of a full-function EV with PbA batteries is only $200 per ton (see Table 4.17), yet the lower end of the cost-effectiveness range becomes $50,000 per ton once transition costs are included (see Table 6.3). This means that the lifecycle costs of ZEVs must be quite close to those of PZEVs if costs per ton are not to rise to high levels (say, more than $50,000 per ton).

Emission reductions from city EVs using NiMH batteries cost less than those from full-function EVs with NiMH batteries do, but the cost per ton is still high. Including transition costs, estimated cost per ton runs from $150,000 to $470,000. In Subsection 4.7, we conclude that the lifecycle costs of city EVs with PbA batteries may be less than those of small ICEVs in volume production. In this case, the cost per ton would be negative, even including transition costs (-$20,000 per ton). Two important caveats are warranted, however. First, most manufacturers are not using PbA batteries in their city EVs, which suggests that there are important design or
performance disadvantages to using PbA batteries in city EVs. Second, there is some chance that the cost per ton for a city EV with PbA batteries will be low, but there is also a good chance that it will be quite high. The low end of the range is based on optimistic assumptions about the parameters that determine lifecycle costs, but the upper end of the range ($250,000) is based on parameter values that are no less likely.

DHFCVs will be very expensive on a cost-per-ton basis when they are first introduced, but they may be a sensible strategy for reducing the emissions of ozone precursors in the long run. We project that in high-volume production, the lifecycle cost of a DHFCV could be less than that of an ICEV. However, a great deal of uncertainty about high-volume DHFCV cost remains: If it turns out to be at the top of the estimated range, it would rise to $310,000 per ton of emissions reduced once transition costs are included. What is more, widespread use of DHFCVs—a precondition for the volume production needed to achieve high-volume costs—depends on the availability of a hydrogen fueling infrastructure. Little progress has been made in developing such an infrastructure, and its development is hardly assured.

6.3 ADDITIONAL FACTORS TO CONSIDER WHEN EVALUATING ZEV PROGRAM

Our cost-effectiveness estimates do not capture all potential costs and benefits of the vehicles that manufacturers may use to satisfy ZEV program requirements. Here we discuss several additional considerations that might enter into decisions on whether to modify the program. We first examine several of the program’s uncounted potential benefits:

- technology forcing
- job creation
- insurance against disappointments in ICEV emission performance
- reduced dependence on foreign oil
- reductions in vehicle emissions other than NMOG and NOx.

We then consider several uncounted potential costs:

- decreases in new vehicle sales
- increases in vehicle miles traveled
- emission reductions in all areas rather than only where there are air quality problems
- offsetting interactions with other programs.

These factors will tend to increase the estimates of cost per ton that we have presented so far.

Uncounted Potential Benefits

Technology Forcing. Our estimates of costs in volume production are based on what is
currently known about EV technology. It may be that requiring automakers to manufacture large numbers of EVs will lead to unanticipated technological advances that will substantially reduce the cost per ton of emissions reduced. Such “technology-forcing” regulation is often held to be an effective means of overcoming market failures (e.g., the failure to consider pollution costs in designing vehicles) because it compels innovation that would not otherwise occur. In evaluating the ZEV program, policymakers need to assess the likelihood that the program will produce unforeseen breakthroughs in EV technology.

Indeed, since their inception in the 1960s,9 most automobile emission regulations have been technology forcing (Brown et al., 1995). The first major federal regulation, Title II of the Clean Air Act of 1970, required 90 percent reductions in hydrocarbon and carbon monoxide emissions by 1975 and in NOx emissions by 1976—standards that were “a function of the degree of control required, not the degree of technology available at the time.”10 Domestic automakers fought the regulations, calling them technically infeasible and ruinously expensive.11 The technology-forcing provisions of subsequent regulations, such as the Corporate Average Fuel Economy (CAFE) standards, the California LEV I program, and the 1990 Clean Air Act Amendments, have met with similar resistance from domestic automakers.

Despite the resistance, however, the automotive industry has made remarkable progress in emission control. Against this backdrop, a CARB official responding to an automaker’s objection to the ZEV program recently declared that “projections of future technologies must be viewed in the context of these remarkable advancements that have been achieved by the auto industry” (CARB, 2001f). The thinking is, if technology-forcing regulations on ICEVs have induced important technological breakthroughs, why should the ZEV program not do the same?

Even though regulation has induced development of ICEV emission control technologies, it does not necessarily follow that automakers will uncover technological breakthroughs that will make BPEV’s commercially viable. First of all, despite more than $500 million having been

9California enabled the promulgation of automobile emission controls in the Motor Vehicle Pollution Control Act of 1960, with the first regulations taking effect in 1965. Federal regulations were enabled by the Motor Vehicle Air Pollution Control Act of 1965 and were implemented in 1968 (Percival et al., 1992).

10S. Report No. 91-1198, 91st Cong., 2nd Sess. 24 (1970). A Senate staffer noted that the 90 percent figure was “a back of the envelope calculation. . . . We didn’t have any particular methodology. We just picked what sounded like a good goal” (Easterbrook, 1989).

11A GM vice president warned that outfitting its fleet with catalytic converters raised the “prospect of an unreasonable risk of business catastrophe . . . [and] complete stoppage of the entire production.” A Ford official claimed that it would “cause Ford to shut down and would result in: 1) reduction of gross national product by $17 billion; 2) increased unemployment of 800,000; and 3) decreased tax receipts of $5 billion at all levels of government so that some local governments would become insolvent” (California ZEV Alliance, 2001).
spent on EV battery development since 1995 by battery makers, the automobile industry, and the United States Advanced Battery Consortium (Anderman, Kalhammer, and MacArthur, 2000), full-function EVs will still have limited range and will cost substantially more than ICEVs for the foreseeable future. The Battery Technology Advisory Panel (BTAP) found that major technological advances would be required to reduce costs significantly and that they were unlikely for the next six to eight years (Anderman, Kalhammer, and MacArthur, 2000). In spite of much ingenuity and resolve, the sought-after dramatic breakthrough just has not happened.

Second, the context of technology forcing in the ZEV program is different from that of the ICEV regulations. The ICEV regulations set performance standards for fleet emissions and leave it to automakers to figure out how to meet them. The ZEV program in effect tells manufacturers that they have to meet part of their fleet NMOG requirement with a special type of vehicle—a ZEV. The ZEV program is thus mandating a particular approach to reducing vehicle emissions. Even if BPEVs turn out to be a dead end, it can be argued that the ZEV program accelerated the development of the motors, controllers, and advanced batteries that may make fuel-cell vehicles economical. Research on BPEVs likely also sped the development of GHEVs. However, there is a risk that the ZEV program is forcing technology in the wrong direction. It may be that the most cost-effective way to reduce emissions is to build vehicles that have very low, but not zero, emissions. Forcing companies to build ZEVs may divert attention from more-promising areas, such as more-effective control technologies for heavier light-duty trucks (LDT2s) or for consumer products and other stationary sources.

Thus, it does not make sense to proceed with the ZEV program solely based on the conviction that the technologies that make ZEVs attractive will materialize. The risk is that a large social investment in building thousands of high-cost vehicles will yield little or no return and that other, more-attractive options will be overlooked.

**Job Creation.** The ZEV program has compelled automakers and their suppliers to engage in substantial research and development (R&D) to meet future standards, and these R&D expenditures yield a variety of economic benefits through the creation of R&D jobs and the attendant multiplier effects. Any such benefits are not captured in the cost-effectiveness estimates presented above.

Many California companies, including the state’s aerospace giants, have experience in the advanced materials and microelectronics that EVs require, and the Los Angeles area is home to many specialty and aftermarket auto component companies. A regional policy center found

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12 For an examination of the so-called secondary benefits of ZEVs, see Burke, Kurani, and Kenney, 2000.

13 EVs require a large number of components and manufacturing processes not shared with
over 400 companies in the Los Angeles area with the capability to manufacture EVs (Reinhold, 1992). A CALSTART survey identified over 100 companies in California with ties to EV R&D and manufacturing, and the great majority of survey respondents reported that the ZEV program was instrumental to their firm’s existence and continued growth (Burke, Kurani, and Kenney, 2000). CALSTART estimated that in 2000 there were approximately 3,500 employees at these EV-related companies, with about 800 of their jobs attributed to the program. An analysis of the potential for job creation in Los Angeles estimates that if 10 percent of the cars sold in California were EVs produced in Los Angeles County, over 24,000 jobs would be added to the local economy. If the region specialized in EV components rather than assembly, approximately 10,000 jobs would be added (Wolff et al., 1995). A 1994 CARB staff report predicted that the ZEV program would yield significant economic growth in California (55,000 new jobs by 2000, and 70,000 by 2010) because 70 percent of the parts in a ZEV would be different from those in ICEVs (Reed, 1997). The California Electric Transportation Coalition predicted that battery manufacturing alone could generate 10,000 jobs in the state by 2005 (Brown et al., 1995).

There are many reasons to be skeptical about the supposed economic benefits of the ZEV program. It was formulated in the early 1990s, when California manufacturing was mired in a recession and the aerospace industry was hard hit by the decline in defense spending after the Cold War ended. The above estimates of job generation are less credible (or less meaningful) in periods of full employment, as have been enjoyed in the state in recent years. Even if there are net employment gains in California, jobs might be created at the expense of workers in traditional automotive industries elsewhere in the country.

Furthermore, a shift to EVs may actually yield a net decrease in total auto manufacturing employment, since EVs have far fewer parts and are simpler to assemble than conventional automobiles. Wolff et al. (1995) found that every $1 billion in final demand for EVs removes about 4,000 jobs, and that if EVs were to replace all conventional vehicles, nearly 300,000 jobs would be lost. Studies finding very high manufacturer costs for compliance with the ZEV program (the so-called “ZEV tax”) also find an associated reduction in employment levels in California. One such report, by National Economic Research Associates (2000), estimates that the program, as revised in January 2001, will result in a loss of 10,000 jobs by 2020.

**Insurance Against Disappointments in ICEV Emission Performance.** The ZEV program also provides some insurance against the possibility that the lifetime emissions of PZEVs and other very clean ICEVs do not turn out to be as low as currently projected. This is

conventional vehicles and, at least in the initial years of the program, will be built in small batches rather than in continuous assembly lines.
another benefit that is difficult to quantify. PZEVs have yet not been sold, and it will be many years before their in-use emissions can be verified. It may turn out that the on-board diagnostics (OBD) systems that monitor emission performance do not work well when emissions are at such low levels, or that emission control systems deteriorate faster than expected. The ZEV program does provide some insurance, but the question is, at what cost. Other types of insurance may be more cost-effective—e.g., research on how to further reduce emissions from stationary sources and off-road and diesel vehicles.

**Reduction of Dependence on Foreign Oil.** The U.S. dependence on foreign oil, and particularly on oil from the Middle East, concerns many policymakers because of the potential uncertainty in supply and because of the cost of maintaining security forces abroad to decrease that potential uncertainty. Greater use of BPEVs, DHFCVs, and GHEVs entails less gasoline use and thus, presumably, lower imports of foreign oil. BPEVs lower gasoline use because most of the electricity that would charge EVs in California would be generated using coal, natural gas, nuclear energy, or hydro power. DHFCVs lower gasoline use because the hydrogen that powers fuel cells would likely be generated from natural gas, not oil. GHEVs lower gasoline use because they are more energy efficient.

To provide a rough estimate of how the ZEV program might affect oil use in California, we assume that manufacturers satisfy the program by producing as many PZEVs and GHEVs as allowed and satisfy the ZEV proportion of the program with full-function EVs (see Subsection 3.2 for a discussion of the various production scenarios). We then calculate the amount of gasoline displaced annually and the barrels of oil displaced, assuming one barrel of oil yields 19.5 gallons of gasoline. As can be seen in Figure 6.1, the amount of oil displaced rises from roughly 250,000 barrels a year in 2003 to nearly 2 million barrels a year in 2030.

To put these reductions in perspective, consider that almost 7 billion barrels of oil are consumed annually in the United States, with California accounting for approximately 10 percent of the total (California Academy of Sciences, 2001). The United States imports approximately 950 million barrels of oil a year from the Middle East (Energy Information Administration, 2001). Thus, even at 2 million barrels a year, the amount of oil displaced by the ZEV program is small relative to total oil usage in California and total oil imports from the Middle East. Of course, the amount of oil displaced will rise if the prevalence of ZEVs or hybrids increases in the state and as they spread to other parts of the country. For example, if EVs had accounted for one-quarter of the miles driven statewide in 2000, oil use would have been nearly 100 million barrels

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A high enough penetration of ZEVs and hybrids in California and other states would eliminate the need to import oil from the Middle East.

Although difficult to quantify, there is a monetary cost connected with maintaining the flow of oil from the Middle East. According to the U.S. Department of Energy,

[The cost of m]aintaining the uninterrupted flow of oil from the Gulf region is high—as much as $57 billion per year. The U.S. General Accounting Office estimated that the cost of U.S. military and foreign aid programs in the Gulf area from 1980 to 1990 was as high as $365 billion. When military and energy security factors are taken into consideration, the true cost of oil is as high as $100 per barrel or $5 a gallon. . . . And this doesn’t take into consideration the cost of actual military action to defend our interests in the Persian Gulf. Our most recent experience with this was the Persian Gulf War which cost $61 billion and loss of priceless human lives (DOE, 2001).

These figures suggest that the gains from reducing Middle East oil imports are high. But these gains probably cannot be realized unless oil imports from the Middle East are substantially or completely reduced, since slight reductions would most likely have little effect on military and security expenditures in this area.

The ZEV program may thus reduce gasoline use and perhaps dependence on Middle East oil. However, the benefits most likely would be great only if the United States ceases importing

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Figure 6.1—Barrels of Oil Displaced Annually by ZEV Program

Although difficult to quantify, there is a monetary cost connected with maintaining the flow of oil from the Middle East. According to the U.S. Department of Energy,

[The cost of m]aintaining the uninterrupted flow of oil from the Gulf region is high—as much as $57 billion per year. The U.S. General Accounting Office estimated that the cost of U.S. military and foreign aid programs in the Gulf area from 1980 to 1990 was as high as $365 billion. When military and energy security factors are taken into consideration, the true cost of oil is as high as $100 per barrel or $5 a gallon. . . . And this doesn’t take into consideration the cost of actual military action to defend our interests in the Persian Gulf. Our most recent experience with this was the Persian Gulf War which cost $61 billion and loss of priceless human lives (DOE, 2001).

These figures suggest that the gains from reducing Middle East oil imports are high. But these gains probably cannot be realized unless oil imports from the Middle East are substantially or completely reduced, since slight reductions would most likely have little effect on military and security expenditures in this area.

The ZEV program may thus reduce gasoline use and perhaps dependence on Middle East oil. However, the benefits most likely would be great only if the United States ceases importing

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15 The number of vehicle miles traveled in 2000 was 300 billion.
substantial amounts of Middle East oil. Also, there may be much more cost-effective ways to reduce gasoline use—e.g., by increasing the Corporate Average Fuel Economy (CAFE) standard or by switching to alternative fuels, such as compressed natural gas, that produce low, but non-
zero, emissions. Alternatives should be investigated before a great deal of weight is put on the ZEV program’s potential to reduce dependence on foreign oil.

**Reductions in Vehicle Emissions Other Than NMOG and NOx.** Our analysis of cost-effectiveness considers reductions in the emissions of NMOG and NOx only. ZEVs will also reduce emissions of other pollutants such as particulates, carbon monoxide, and the greenhouse gas, carbon dioxide. In evaluating the importance of these other emission benefits, policymakers need to consider both the magnitude of the reductions and their value. For example, most areas of the state are in compliance with carbon monoxide standards, so additional carbon monoxide reductions may not be of great value. ZEVs may reduce carbon dioxide emissions, but there may be more cost-effective ways to achieve the same end. For example, it may be more cost-effective to raise the CAFE standard than to require ZEVs. The GHEVs recently offered for sale by Honda and Toyota suggest that raising the CAFE standard may not be as expensive or as demanding of lifestyle changes as previously thought.

**Uncounted Potential Costs**

**Feedback on New Vehicle Sales.** The ZEV program may cause manufacturers to increase the prices of conventional new vehicles in order to recover the costs of developing and producing ZEVs. Any such increase in new vehicle prices will tend to reduce the sales of new vehicles, slow the retirement of older vehicles, and gradually increase the age of the fleet (Gruenspecht, 1982a, 1982b). Older vehicles, because of deterioration and the less stringent emission requirements in force when they were manufactured, tend to have higher emissions than newer vehicles do. Thus, increases in new ICEV prices will tend to increase fleet emissions over time and to offset, at least to some extent, the emission benefits of ZEVs.

Whether the price increases will be large enough to overwhelm the emission benefits of ZEVs has been hotly debated. Harrison et al. (2001) argue that manufacturers will only increase the price of new vehicles sold in California and that those increases will be large enough to increase fleet emissions in California at least through 2020. CARB (2001e) counters that manufacturers will spread costs nationwide, and that even if they did not, the magnitude of the increase in California and the consequent effect on emissions would be much less than predicted by Harrison et al.

There are good arguments on both sides of this debate. The ZEV program does create a cost of selling an additional ICEV in states that have adopted the program.16 Simple models of profit maximization conclude that manufacturers set prices on products according to the costs of

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16For every ICEV sold, manufacturers must sell a fraction of a ZEV.
producing and selling those products. The ZEV program creates no additional costs in states that have not adopted the program, so prices should not rise in those states. Complications in the real world raise doubts about this reasoning, however. First, competition from small- and intermediate-volume manufacturers not subject to the pure ZEV portion of the program may dissuade the large-volume manufacturers from concentrating price increases in California. Now that the cutoff between intermediate- and large-volume manufacturers has risen to 60,000 vehicles per year (from 35,000 previously), large price increases by large-volume manufacturers may have real consequences for their market share. Second, manufacturers have spread costs outside the markets that generate them in a number of circumstances. Dixon and Garber (1996) were told by observers inside and outside the auto industry that companies typically spread vehicle transportation and delivery costs across geographic areas. The Green Car Institute found that manufacturers had recently dropped the $100 typically added to a vehicle’s retail price to cover California emission requirements because “from a market standpoint the automakers viewed the separate charge for the California emissions programs as negative to their other marketing efforts” (Green Car Institute, 2001, p. 24). Manufacturers may be less likely to spread costs if the additional costs are large (as opposed to modest, as in the case of transportation and shipping charges); but in any case, uncertainty remains about the ZEV program’s effect on new vehicle prices and any consequent indirect effect on fleet emissions in California.

Even if manufacturers spread costs nation- or even worldwide, there may be some reductions in new vehicle sales and, consequently, increases in emissions both inside and outside California. Thus, consideration of the ZEV program’s feedback on new vehicle sales would lead to an increase in the cost-per-ton estimates presented here, but the overall significance of the effect is uncertain.

**Increase in Vehicle Miles Traveled.** Studies have found that increases in fuel economy (or reductions in fuel price) increase the amount of driving done by households. For example, Greene, Kahn, and Gibson (1999) found that about 20 percent of projected energy savings due to increased fuel efficiency were offset by increases in miles driven. Such might be the case for the vehicles examined in our analysis. As shown in Table 4.17, the operation and maintenance costs of full-function EVs, city EVs, GHEVs, and DHFCVs may be less than those of a comparable standard ICEV in volume production. These lower costs may induce more driving and thus offset some of the emission benefits assumed. The result will be higher costs per ton of emissions reduced than those reported here.18

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17Some of these increases will undoubtedly be in areas with good air quality and thus will generate little benefit.

18An increase in vehicle miles traveled can also cause an increase in congestion. Parry and Small
Emission Reductions in All Areas Rather Than Only Where There Are Air Quality Problems. The ZEV program applies throughout California and will result in ZEVs and PZEVs in areas of the state that have no air quality problems. Emission reductions in these areas are of little benefit. Further analysis is needed to determine the importance of this effect in the cost-effectiveness calculations, but any effect will tend to increase cost per ton if “ton” is redefined to restrict emission reductions in areas that need reductions.

Offsetting Interaction with Other Programs. The ZEV program interacts with a number of other regulations that affect its overall impact on emissions. Examples include California’s fleet-average NMOG requirement and the federal Corporate Average Fuel Economy (CAFE) standards.

CARB requires that new vehicles sold by each manufacturer meet a fleet-average NMOG requirement. Each different exhaust emission category (the SULEV exhaust standard is one such category) is assigned an NMOG factor, and the average across all vehicles sold by a manufacturer during a year is its fleet-average NMOG. ZEVs, ATPZEVs, and PZEVs count in the fleet-average NMOG calculation, so the ZEV program allows vehicles that do not generate ZEV credits to be dirtier than they otherwise would be. This feedback offsets some of the benefits of the vehicles used to satisfy ZEV program requirements. Accounting for such a feedback will increase the costs per ton above those reported here. It should be noted, however, that this aspect of California’s ZEV program could be changed.

The CAFE regulations allow an analogous feedback. Alternative fuel vehicles are granted generous CAFE credits. Thus, the ZEV program allows the fuel efficiency of gasoline vehicles to decline, increasing indirect emissions of NMOG and NOx, as well as of carbon dioxide. The decrease in fuel economy may also offset some of the potential benefit the ZEV program has for reducing dependence on foreign oil. Again, this regulatory provision could be changed. In fact, a recent National Research Council study (2002) recommended that CAFE credits for alternative fuel vehicles be eliminated.

(2002) found the costs of increased congestion to be larger than the costs of increased pollution, although their analysis did not address California or the South Coast Air Basin in particular.

As discussed in Subsection 5.1, indirect emissions are negatively related to fuel economy, whereas exhaust emissions and evaporative emissions are not. Exhaust emissions are not related to fuel economy because the emission standards are set in grams per mile. Evaporative emissions are not related to fuel economy because standards for all but running emissions are specified as emissions per test procedure, and standards for running emissions are specified in grams per mile.