3. TECHNOLOGIES FOR MEETING ZEV PROGRAM REQUIREMENTS AND PRODUCTION VOLUME ESTIMATES

This section provides an overview of the vehicle technologies that auto manufacturers may use to meet the ZEV program requirements. (These technologies are described in greater detail in Section 4, where we develop cost estimates.) This section also presents the production volumes we used in our analysis, which are important in determining vehicle unit cost. The production projections are not meant to be precise estimates of the numbers of vehicles that will be produced to meet the program requirements. Rather, they are rough estimates of the number of vehicles that may be produced if a particular technology is used in a meaningful way to meet the requirements.

3.1 TECHNOLOGIES FOR MEETING ZEV PROGRAM REQUIREMENTS

As discussed in Subsection 1.1, CARB has created three technology categories within the ZEV program: ZEVs, partial zero emission vehicles (PZEVs), and advanced technology partial zero emission vehicles (ATPZEVs). Large-volume manufacturers must meet a minimum portion of the program requirements with ZEVs and have the option to satisfy other portions with PZEVs and ATPZEVs. The following paragraphs describe the types of vehicles that manufacturers might plausibly produce in each category.

ZEVs

ZEVs can be based on a number of energy storage technologies (e.g., batteries, capacitors, flywheels, fuel cells), but only battery-powered electric vehicles (BPEVs) and fuel-cell vehicles are actively being pursued by the large-volume manufacturers. We first discuss the various types of BPEVs that may be used to meet program requirements, before turning to fuel-cell vehicles.1

Battery-Powered Electric Vehicles. Until a few years ago, the only vehicles that manufacturers considered for meeting ZEV program requirements were BPEVs similar in size to many vehicles on the road today and freeway capable. These “full-function EVs” typically have top speeds greater than 65 miles per hour, meet U.S. highway safety standards, include amenities such as air conditioning, and have reasonable acceleration (although often less than that of a comparable internal combustion engine vehicle, or ICEV). The major shortcoming of these vehicles is their range—i.e., the distance they can travel on a single charge. While battery

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1ZEVs may have emissions associated with the production, marketing, and distribution of the fuel they use. For example, power plants generate emissions when producing electricity. These indirect emissions are discussed in Subsection 5.1.
technology has improved during the last decade, barring some further technological breakthrough, it is unlikely that the full-function EVs that manufacturers would produce starting in 2003 would have a real-world range much over 100 miles. The large-volume manufacturers have produced a number of different full-function EVs to date; Appendix A details their characteristics.

Faced with the high production costs of full-function EVs and large projected losses per vehicle, some manufacturers have developed BPEVs that are much smaller than the typical ICEVs they sell in the United States. These “city EVs” have limited top speed, acceleration, and range. They typically seat two passengers and meet highway safety standards but, with a top speed of only 50 to 60 miles per hour, are not designed for regular freeway use. They usually can travel 50 to 60 miles on a single charge. City EVs will soon be available from some automakers (see Appendix A).

“Neighborhood EVs,” which are intended for local travel on low-speed-limit routes (especially in and around planned communities), can also be used to satisfy the program requirements. Resembling golf carts (although some have doors), the current models have a range of about 30 miles and are limited by law to a top speed of 25 miles per hour. The National Highway Transportation Safety Administration requires that they have safety features, including lights, mirrors, a windshield, and seat belts, but they are not required to meet the other safety standards of vehicles that can travel at higher speeds. Because CARB believes that neighborhood EVs will not displace many of the miles traveled by vehicles currently on the road, it has severely discounted the number of ZEV credits such vehicles generate starting in model year 2006. We thus think it unlikely that neighborhood EVs will play much of a role in satisfying the ZEV program requirements, except perhaps in the very early years, and we do not consider them further in our analysis.

**Direct Hydrogen Fuel-Cell Vehicles.** A fuel-cell vehicle is powered by an on-board fuel cell that generates electricity that drives an electric motor. The relatively low-temperature proton exchange membrane (PEM) fuel-cell stack has been singled out by major automakers as the fuel-cell technology choice for autos.\(^2\) PEM fuel-cell vehicles can be fueled with hydrogen, methanol, or even gasoline, but only vehicles fueled with hydrogen qualify as ZEVs. We refer to these as direct hydrogen fuel-cell vehicles (DHFCVs). The other types require a reformer that produces hydrogen from methanol or gasoline in a process that generates carbon monoxide emissions, and there are evaporative emissions associated with gasoline and methanol. It appears that DHFCVs

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\(^2\)PEMs are also referred to as polymer electrolytic membranes or polymer electrolyte membranes, but proton exchange membrane is the most common term.
will allow a greater range than BPEVs—the storage capacity of their hydrogen fuel tanks has increased enough that DHFCVs can travel upwards of 180 miles on a single fill-up. (Characteristics of recent prototypes are provided in Subsection 4.1.)

Several of the large-volume manufacturers have developed prototype DHFCVs, but it appears likely that these vehicles will be available only in very small quantities before 2006. Honda recently announced that it will sell DHFCVs to fleets in California in 2003 but expects to make “less than a couple of handfuls” available (Hydrogen & Fuel Cell Letter, 2002). At the Tokyo auto show in October 2001, Toyota announced its intention to start selling a compressed hydrogen fuel-cell vehicle beginning in 2003, with planned sales of 30 to 50 per year (Schreffler, 2001). Ford plans to offer its Focus DHFCV in California starting in 2004. Initial production is likely to be “in the tens” of vehicles, according to Ford (Hydrogen & Fuel Cell Letter, 2002).

The infrastructure to fuel DHFCVs remains a major stumbling block. Various options are being considered, including fueling stations (perhaps part of existing gas stations) with reformers that generate hydrogen from natural gas.

Partial Zero Emission Vehicles

To qualify for PZEV credits, vehicles must meet very stringent emission, durability, and warranty standards. They must be certified to CARB’s

- 150,000-mile super ultra low-emission vehicle (SULEV) exhaust emission standard for light-duty vehicles (LDVs);
- zero evaporative emission standard; and
- on-board diagnostics (OBD) system requirements. The OBD system must be able to detect whether the emission standards have been even very slightly exceeded.

In addition, the vehicle warranty on emission control equipment must be extended to 15 years or 150,000 miles, whichever occurs first (CARB, 2002, p. 4).

Current CARB regulations outside the ZEV program require manufacturers to begin producing vehicles that meet SULEV exhaust standards by 2009, so PZEVs do not improve on the tightest tailpipe emission category currently in place. PZEVs must be certified at 150,000 miles, however. Standard SULEVs are certified at 120,000 miles, although their manufacturers can opt to certify them at 150,000 miles in return for greater emission credits.4 Tighter

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3The certification standard for ultra low emission vehicles (ULEVs) is 0.04 grams per mile, so once the fleet-average NMOG requirement falls below 0.04, manufacturers must start producing SULEVs. The fleet-average NMOG requirement first falls below 0.04 in 2009 (CARB, 2001g, pp. E-5, E-16).

4Manufacturers must demonstrate that their vehicles meet emission requirements before they can be certified for sale in California. Such demonstrations are usually done using protocols that simulate
regulations on evaporative emissions will be phased in between 2003 and 2006, but the zero evaporative standard represents a further reduction.\(^5\) The 15-year/150,000-mile warranty extends the comprehensive 3-year/50,000-mile emission warranty currently required in California.\(^6\) Over the years, CARB has created progressively more-stringent vehicle emission control categories. PZEVs are the next step. As we discuss in Section 5, while not zero, NMOG and NOx emissions from PZEVs are exceedingly small.

**Advanced Technology Partial Zero Emission Vehicles**

An ATPZEV is a PZEV that includes components common to ZEVs—e.g., an advanced battery that is integral to the operation of the power train or an electric power train. The hybrid EVs recently introduced in the United States by Toyota and Honda will qualify as ATPZEVs once they meet the PZEV emission standards.\(^7\) These vehicles run on gasoline and are propelled by a drive train that integrates an electric motor and an internal combustion engine. While other types of ATPZEVs are possible, these gasoline hybrid electric vehicles (GHEVs) appear to be the only ATPZEVs currently being developed by manufacturers.\(^8\) The advantage of a GHEV to the consumer is improved gasoline mileage—GHEV fuel efficiency can be 30 to 50 percent higher than that of a comparably sized standard ICEV.

Because ATPZEVs must meet the same emission standards as PZEVs, they offer no reductions in NMOG or NOx exhaust emissions or evaporative emissions. GHEVs, however, generate less carbon dioxide per mile because of their better fuel efficiency. As we discuss in Section 5, lower fuel use also means lower upstream emissions from the production and distribution of fuel.

**3.2 PRODUCTION VOLUMES USED IN COST ANALYSIS**

Our ultimate goal in this study was to evaluate the promise of the different technologies for meeting ZEV program requirements. To do this we evaluated the cost-effectiveness of each technology when vehicles are produced in high volume. But we also had to consider the costs component aging in the lab and extrapolated deterioration rates from road tests on a few demonstration vehicles.

\(^5\)The emissions allowed under the zero evaporative standard are very low but not actually zero.

\(^6\)On some emission parts, California requires a 7-year/70,000-mile warranty and the federal government requires an 8-year/80,000-mile warranty, but these warranties are much more limited than California’s 3-year/50,000-mile warranty.

\(^7\)Honda’s vehicle is the Insight, and Toyota’s is the Prius. Ford plans to sell a hybrid version of its Escape sports utility vehicle in 2003.

\(^8\)Grid-connected hybrids can also qualify as ATPZEVs. They can be plugged in and charged; they run on batteries until the batteries run down, at which point the internal combustion engine comes on. No large-volume manufacturers are developing grid-connected hybrids, however.
incurred when production volumes are lower to evaluate the overall cost-effectiveness of these technologies. We present here the production volumes we used in our analysis. These are not meant to be precise estimates of the numbers of vehicles that will be produced to satisfy requirements in California and possibly in the four northeastern states that may also adopt the ZEV program. Rather, they provide rough estimates of the numbers of vehicles that may be produced if a particular technology is used in a meaningful way to meet program requirements.

We developed six different scenarios to capture the range of volumes at which large-volume manufacturers might plausibly produce vehicles to satisfy program requirements. In all scenarios, we assume that manufacturers produce the maximum number of PZEVs allowable. We think this likely because, as discussed in Section 4, the costs of meeting the PZEV standards appear to be modest. Table 3.1 describes the scenarios. In the first two scenarios, manufacturers produce FFEVs to meet their ZEV requirements, but they produce different numbers of ATPZEVs: In scenario 1, they make use of ATPZEVs to the maximum extent possible; in scenario 2, they satisfy only one-half of what they are allowed to meet with ATPZEVs. Toyota and Honda are already selling GHEVs in the United States (although they do not yet meet the PZEV emission and warranty requirements), and Ford has plans to introduce the hybrid version of its Escape sports utility vehicle in 2003. It thus seems almost certain that the large-volume manufacturers will satisfy an important part of the program with GHEVs starting in 2003. Not all manufacturers may choose to produce GHEVs, however, and their popularity with consumers remains uncertain. We thus vary the number of ATPZEVs between the maximum allowed and one-half the maximum.

In scenarios 3 and 4, manufacturers produce city EVs to meet one-half of the ZEV portion of the program. Because city EVs have limited capabilities, we think it unlikely that manufacturers can satisfy more than one-half of the ZEV portion of the program with them. The remaining half is met with full-function EVs.

Manufacturers satisfy the ZEV portion of the program with DHFCVs in scenarios 5 and 6. We concluded above that it is unlikely that DHFCVs will be produced in appreciable volumes before 2006. Thus, in our analysis of DHFCVs, we consider their cost-effectiveness from 2006 on.

For each of these scenarios, we combine projections of the number of vehicles sold per year and the number of ZEV credits generated per vehicle to project the number of vehicles produced each year between 2003 and 2030 (between 2006 and 2030 for DHFCVs). The calculations are quite involved, because the program regulations are complicated (see details in Appendix B). Here we present the resulting range of production volumes for each vehicle type. The lower end of the range for full-function EVs is based on the number in scenario 1 when the
program applies only in California; the upper end is based on the number in scenario 2 when the
program applies in California and the four northeastern states that may adopt the program.

Table 3.1
Assumptions Used to Develop Production Volume Scenarios

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Vehicle Type</th>
<th>Full-Function EV</th>
<th>City EV</th>
<th>ATPZEV</th>
<th>DHFCV</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Full-Function EV scenarios</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Scenario 1</td>
<td></td>
<td>Meet full ZEV</td>
<td>0</td>
<td>Maximum possible</td>
<td>0</td>
</tr>
<tr>
<td>Scenario 2</td>
<td></td>
<td>Meet full ZEV</td>
<td>0</td>
<td>1/2 maximum possible</td>
<td>0</td>
</tr>
<tr>
<td><strong>City EV scenarios</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Scenario 3</td>
<td></td>
<td>Meet 1/2 ZEV</td>
<td>Meet 1/2 ZEV</td>
<td>Maximum possible</td>
<td>0</td>
</tr>
<tr>
<td>Scenario 4</td>
<td></td>
<td>Meet 1/2 ZEV</td>
<td>Meet 1/2 ZEV</td>
<td>1/2 maximum possible</td>
<td>0</td>
</tr>
<tr>
<td><strong>DHFCV scenarios</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Scenario 5</td>
<td>0</td>
<td>0</td>
<td>Maximum possible</td>
<td>Meet full ZEV requirement</td>
<td></td>
</tr>
<tr>
<td>Scenario 6</td>
<td>0</td>
<td>0</td>
<td>1/2 maximum possible</td>
<td>Meet full ZEV requirement</td>
<td></td>
</tr>
</tbody>
</table>

Overall sales volumes, and thus the number of vehicles required in the different scenarios, are 75
percent greater when the program applies in California plus the four northeastern states rather
than in California alone. A similar approach is used to determine the number of city EVs,
ATPZEVs, and DHFCVs.

The results are presented in Figures 3.1 through 3.5. Production of full-function EVs
ranges from 4,000 to 10,000 units in 2003 (see Figure 3.1). In scenario 1, it rises to roughly
90,000 vehicles per year in 2018; the gradual rise thereafter tracks the gradual increase in total
vehicle sales over time. Production volume reaches just under 40,000 units in 2018 in scenario 2.
To put these numbers in perspective, California sales of vehicles subject to the pure ZEV portion
of the program are expected to be roughly 1.0 million in 2003 and 1.7 million in 2012 after
heavier light-duty trucks (i.e., LDT2s, which are LDTs with a loaded vehicle weight of >3,750
pounds and gross vehicle weight rating of ≤8,500 pounds) are included in the base to calculate
program requirements.9,10 The figures are roughly 1.75 million and 3.1 million, respectively, if

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9This is only for sales by the six large-volume automakers. They account for roughly 85 percent of
LDV sales in California (Ward’s Communications, 1999, pp. 31-36).

10CARB’s EMFAC2000 emission model (CARB, 1999b) estimates that slightly over 21 million
LDVs are on the road in California in 2002.
Figure 3.1—U.S. Production Volume Range for Full-Function EVs
(Based on Scenarios 1 and 2)

Figure 3.2—U.S. Production Volume Range for DHFCVs
(Based on Scenarios 5 and 6)
Figure 3.3—U.S. Production Volume Range for City EVs
(Based on Scenarios 3 and 4)

Figure 3.4—U.S. Production Volume Range for GHEVs
(Based on All Scenarios)
the four northeastern states are included. The ranges for DHFCVs are the same as those for full-function EVs, except for 2003 to 2006, when production is assumed to be zero (see Figure 3.2). This is because DHFCVs are assumed to generate the same number of ZEV credits as full-function EVs do.

City EV volumes range from 5,000 to 12,000 in 2003 and from roughly 25,000 to 70,000 in 2030 (see Figure 3.3). Note that full-function EVs are also produced in the city EV scenario. In our city EV cost analysis, we take into account the combined volumes of batteries and electric drive components needed to produce these two types of EVs.

The number of ATPZEVs (which we assume are GHEVs) starts low because of phase-in multipliers but then rises quickly (see Figure 3.4). The volume paths for PZEVs are shown in Figure 3.5. The difference between the low- and high-volume scenarios for PZEVs is due

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11 The breakdown of total 1998 sales of passenger cars in the five states that have adopted the program is: California, 57 percent; New York, 29 percent; Massachusetts, 12 percent; Maine, 1 percent; Vermont, 1 percent. Passenger cars account for about 90 percent of total sales of passenger cars plus LDT1s (i.e., LDTs with a loaded vehicle weight of ≤3,750 pounds) (Ward’s Communications, 1999, pp. 31-33).

12 The number of city EVs drops slightly between 2004 and 2007 because of the details of the phase-out of the extended range multiplier and the phase-in of the high-efficiency multiplier.

13 The PZEV scenarios include PZEV production by intermediate-volume manufacturers, which we assume satisfy their entire program requirements with PZEVs. Based on the number of small-volume
solely to our assuming that the program applies in California only or in California plus the four northeastern states.

manufacturers reported by CARB (2000b, p. 8), intermediate- and large-volume manufacturers account for roughly 95 percent of vehicle sales in California. (As noted above, large-volume manufacturers alone account for roughly 85 percent of vehicle sales.)