VEHICLE ELECTRIFICATION POLICY STUDY

Task 1 Report:

TECHNOLOGY STATUS

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EXECUTIVE SUMMARY

ICCT's Vehicle Electrification Policy Study seeks to evaluate policies that can achieve motor vehicle emission reductions beyond those attainable with traditional tailpipe standards. The study is focused on "pure" electric vehicles—battery electric vehicles (BEVs), fuel cell electric vehicles (FCEVs), and combinations thereof—and on the efforts of governments to encourage their adoption. The pending modification of the California Zero Emission Vehicle (ZEV) program, due to be considered by the Air Resources Board in October 2011 in conjunction with the LEV III criteria pollutant and greenhouse gas regulations, is a central concern of the study.

This study identifies and promotes policies that support vehicle electrification, focusing on the California ZEV program. In light of the history of the ZEV program and its surrounding controversy, it is helpful to clearly and carefully define the overall goal of vehicle electrification policy. ICCT believes the goal is to foster a successful long-term transition to zero-carbon electric drive transportation.

The ICCT study is organized around five tasks, with the results of each task presented in a separate policy report. This document reports ICCT analysis and findings regarding Task 1, Technology Status. The purpose of this report is to review the current status of BEV and FCEV technology, and to use the results of that review to provide insight into the scale of future requirements under the California ZEV program. This report thus provides a policy-relevant updated compilation of recent work. ARB staff have asked for comment on the issues addressed herein, and this report is intended to assist staff in their deliberations.

This study in large part is directed toward providing information that will feed into the consideration of modifications to the ZEV program. The ZEV regulation was adopted in 1990 and has undergone significant periodic modifications since that time, most recently in 2008. In its current form, the program calls for increasing placement of ZEVs by manufacturers over successive 3-year phases. Although the regulation requires the placement of ZEVs, it is not a mandate for particular technologies but rather a technologically neutral performance standard under which a portion of the fleet must meet a tailpipe emission standard of 0 g/mi.

At this stage in the development of the ZEV program and vehicle electrification programs worldwide, several broad trends are evident:

- The California ZEV program is no longer the only governmental driver of progress in passenger vehicle electrification. Many other jurisdictions are pushing vehicle electrification and have active programs under way. Vehicle manufacturers are aggressively pursuing a variety of advanced technologies to secure their competitive positions in the global marketplace. Traditional tailpipe vehicle regulatory programs are no longer the only policies that push for reductions in motor vehicle emissions.

- Policies to encourage vehicle electrification must be mindful of quite different near-term and long-term challenges. In the near term, the goal is commercialization and future job creation, which will be accomplished through successful deployment of the first waves of vehicles and during the ramping up to larger production volumes. In the long term, the focus is on emission reductions and energy security. To have a measurable impact, there must be large numbers of vehicles, and zero tailpipe emission vehicles need to be cost competitive with other technologies.
- Although the global level of support for vehicle electrification is encouraging, major obstacles must be overcome before any pure electric drive vehicle can compete with continually improving conventional power trains and achieve deployment volumes sufficient to make an environmental difference.
- The two main contenders for vehicle electrification—BEVs and FCEVs—are in different stages of development and will have different deployment trajectories.

Battery, fuel cell, and vehicle manufacturers are working vigorously to improve performance on a variety of fronts. For BEVs, the primary technical challenges involve safety, reliability/manufacturability, durability, and cost. For FCEVs, the focus is on durability and cost, as well as providing hydrogen fuel in a cost-effective manner. Although all of these technology issues are important, this report focuses on cost.

Recent cost estimates for FCEVs show the cost dropping over time from several hundred thousand dollars now to roughly $75,000 in 2015 and $50,000 or less in 2020. For batteries, most analysts project the cost per kilowatt-hour (kWh) for BEV batteries to drop from $650 – $1,000 today to $400 – $700 in 2015 and $300 – $500 in 2020, with some projections for 2020 going as low as $150 per kWh.

There have been many studies of the commercialization potential and possible deployment trajectories for advanced vehicles. Although such studies are highly uncertain, they can provide some insight into future production volumes and, hence, the likelihood of achieving the volume-based cost reductions noted earlier. Not surprisingly, various parties differ significantly in their views of ZEV commercialization potential. This report reviews estimates made from four different perspectives: manufacturer production plans, analyst projections, survey data, and governmental targets and goals. Based on a compilation of production plans and other information, the Natural Resources Defense Council (NRDC) concluded that planned deployment of pure electric vehicles (BEVs and FCEVs) in the United States in 2015 will be approximately 227,000 vehicles. A similar analysis by Nomura Research Institute, Ltd., found that global automaker electric vehicle production plans for 2015 add up to about 900,000 vehicles. Analyst estimates for global production in 2015 range from 100,000 to 742,000 vehicles, and estimates for 2020 range from 500,000 to 4 million vehicles. Surveys conclude that 5% of U.S. customers are considering buying an electric vehicle, and 2% say it is likely that they will purchase an electric vehicle in the next 2 years. On the government side, the United States, Germany, the

United Kingdom, France, China, and Japan have all established ambitious targets to have 1 million or more cumulative PHEVs or electric vehicles on the road in the 2015–2020 timeframe.

Achieving these early ZEV deployments will depend in part on the availability of adequate refueling infrastructure. Over the long term, if ZEVs are commercialized, cost competitive over their lifecycle, and deployed in large numbers, the refueling market will evolve to meet their energy demands. In the near term, however, when vehicle numbers are small and the revenue available from vehicle refueling is limited, careful planning and policy support is needed to ensure that infrastructure is available as needed.

The electric vehicle sales targets under consideration by ARB staff for the 2018–2021 period (1.5% to 4%) and the 2022–2025 period (5% to 8%) fall within the range of the electric vehicle penetration estimates from most analysts. Given the climate-driven need for rapid deployment, it can be argued that the ARB ZEV sales mandate for the 2020 timeframe should be set at a level that "locks in" a substantial portion of the deployment already being projected by manufacturers. Although this view may at first glance seem self-evident, it assumes that technology will progress per the manufacturer and analyst projections. Bearing in mind that in the past ARB has had to repeatedly amend the ZEV program to align with slower-than-anticipated technical progress and cost reduction, it also is important to consider what happens in a world where progress does not materialize as expected. In that situation, the per-vehicle cost remains high, and a large ZEV requirement places a significant burden on manufacturers and diverts scarce resources from research and development to deployment. The unique contribution of the ZEV mandate is its ability to sustain research and development during periods of uncertainty and market challenge.

Unlike vehicles that rely on combustion engines for motive power, ZEVs have the potential to be truly zero-emission, but their real-world performance depends on the specific technology pathways used to provide their fuel. Thus, it is important to address the greenhouse gas (GHG) and criteria pollutant emissions and other environmental impacts that result from the production and distribution of the fuel compared with similar impacts from conventional fuels.

In California, taking into account tailpipe and petroleum distribution emissions, vehicle electrification should have a very positive overall effect on ozone precursors and fine particulate emissions. Other states, including states that export electricity to California, have different utility mixes that in some cases rely much more heavily on coal and raise the question of environmental impacts in these other areas. A national Electric Power Research Institute (EPRI)/NRDC study of the emission impact of PHEVs found that most people would experience air quality improvements in ozone and fine particulate levels in the year 2030, whereas a much smaller number (primarily those living near large power plants) would receive disbenefits.

From a GHG standpoint, electric drive vehicles provide a significant well-to-wheels emission reduction compared with conventional petroleum fueled vehicles. Electric drive vehicles are not expected to create significant water pollution, water consumption, or waste management impacts.

Based on the research outlined in this report, ICCT offers the following summary observations:

- ZEV technology is advancing rapidly, with major manufacturer investment in vehicle technology development and deployment.
- There is substantial uncertainty regarding commercialization potential.
- Analyst projections of future production volume for the most part are consistent with the targets set forth by ARB staff at the November 15, 2010, workshop, but caution is advisable.
- Vehicle deployment targets need to be defined from the bottom up (the number that can feasibly be produced in a given timeframe) as well as from the top down (the number needed to meet 2050 GHG reduction targets).
- Over the long run, the ZEV program will transition into the LEV program GHG fleet average. Thus, the mechanism for achieving the 2050 GHG target is, in reality, the fleet average not ZEV production volume.
- Over the long term, the ZEV program can be viewed as a transitional effort to support investment in a broad range of technologies.
- More generally, the ZEV mandate can now be viewed as a “floor,” establishing minimum production requirements that will maintain some level of investment and momentum even if the voluntary programs in other jurisdictions do not move forward as planned.
- ZEV technology provides environmental benefits now, but further efforts will be needed to ensure that, in the future, the vehicles achieve their full emission reduction potential.

As history has shown, it is difficult to predict cost and vehicle deployment trajectories for advanced technology vehicles. Therefore, the relevant question is how should ZEV policy proceed in the face of this uncertainty? ICCT makes the following recommendations based on the assessment of technology status and cost projections:

- ICCT recommends continuation of the ZEV program in recognition of its critical role in encouraging continued long-term technology development.
- ICCT supports ARB staff’s consideration of a firm 2026 transition date, at which point the ZEV requirements would be removed and replaced by reliance on a fleet average GHG standard, while recognizing that additional work is needed.
- ARB staff should begin now to define how upstream GHG emissions from electric drive vehicles can be accurately accounted for in the fleet average

emission calculations. ICCT provides a more complete discussion of this topic in the Task 2 report on metrics.

- ICCT supports the ARB staff proposal to retain, without significantly changing, the existing requirements through 2017. This approach is consistent with viewing the ZEV program as a “floor,” as noted earlier.
- ICCT believes that the regulation should recognize and appropriately credit Enhanced Advanced Technology PZEVs, but there should not be a specific requirement that such vehicles be produced.
- With regard to future deployment targets, for Phase V (2018–2021) ARB staff has proposed a target increasing from 1.5% to 4% of sales, and for Phase VI (2022–2025) a target increasing from 5% to 8% of sales. More aggressive targets would help lock in the deployment numbers anticipated by manufacturers and ensure significant investment in vehicle deployment. On balance, ICCT recommends caution and recommends targets consistent with (although slightly lower than) the ARB proposal when expressed in terms of the number of vehicles required. As discussed in the Task 2 report, ICCT recommends a credit structure that differs somewhat from the ARB staff proposal, such that the percentage requirements set forth by ARB and ICCT are not strictly comparable. Using ICCT’s framework, the percentage requirement would increase from 1.5% to 4% in Phase V and from 7% to 10% in Phase VI. Again, this approach is consistent with viewing the ZEV program as a floor.
- ICCT agrees with ARB staff that cost evaluations should take into account sales outside of California. If other jurisdictions follow through on announced plans, and customers actually purchase the vehicles at the proposed levels, California deployment will be only a portion of global deployment over the next several years.
- ARB staff should explicitly consider LEV III GHG and ZEV interactions with the Low Carbon Fuel Standard, the Renewable Electricity Standard, and emerging federal and state climate policies and, as appropriate, consider regulatory modifications to programs to maximize synergies.

INTRODUCTION

ICCT Vehicle Electrification Policy Study

ICCT has undertaken a Vehicle Electrification Policy Study to evaluate, recommend, and support the adoption of policies that can achieve motor vehicle emission reductions beyond those achieved by traditional tailpipe standards. Although ICCT recognizes the important role that plug-in hybrid electric vehicles (PHEVs) are likely to play in the transition to vehicle electrification, the study is focused on the encouragement of "pure" electric vehicles—battery electric vehicles (BEVs) and fuel cell electric vehicles (FCEVs). These two major electric-drive technology areas are grouped here and in many international policy efforts because of their electric drivetrain commonality, their diversity of potential upstream energy carriers, and their prospects for long-term, ultra-low energy, and emissions impacts. Throughout this project the term *electric vehicle* refers to both BEVs and FCEVs.

The study is focused on California because of the strong policy support across state and local agencies for advanced vehicle technologies and for greenhouse gas (GHG) and criteria pollutant reductions. Public support in California for clean vehicles is strong, as evidenced by the early adoption of technologies such as hybrid electric vehicles at twice the national average. Many California policy windows of opportunity exist, notably the pending modification of the California Zero Emission Vehicle (ZEV) program, due to be considered by the Air Resources Board (ARB) in April 2011 in conjunction with the LEV III criteria pollutant and GHG regulations.

California's motor vehicle criteria pollutant and GHG tailpipe standards are extremely important and are on track to achieve significant reductions. They have been adopted in 10 other states and have set important precedents for federal standards—in many cases, for the development of technology applied globally. In the near term, however, further tightening of GHG standards most likely will lead to incremental improvements in the efficiency of passenger vehicles through measures such as increased combustion efficiency, downweighting, and hybridization. Major barriers to the development and deployment of ZEV advanced technologies are not likely to be overcome through traditional standards alone. Thus, different policy tools are needed to accelerate the deployment of electric vehicles with zero tailpipe emissions.

The study is intended to provide information relevant to the upcoming consideration of modifications to the ZEV program. The study is organized around five tasks, with the results of each task presented in a policy report:

1. *What is the current status of vehicle and infrastructure technology and what are the current and projected costs?*

   On the basis of a review of existing studies, Task 1 provides an overview of technology status and projected costs for BEVs and FCEVs. The report compiles existing estimates of incremental cost over time, taking into account expected technical development and increased production volume. The report also evaluates global deployment projections and compares the likely California share of those deployments to the targets for the ZEV program under consideration by the California ARB staff.

2. *What metrics should be used to measure progress toward ZEV commercialization?*

   Currently the ZEV program requirements are expressed primarily in terms of the number of vehicles to be offered for sale, with adjustments for different types of technology. This approach has the benefit of being tangible and readily verified because it is based on available sales data. Depending on technology progress over time, however, this approach can lead to over- or underinvestment in the various deployment stages. Other metrics that have been used or recommended include componentry-based approaches (such as vehicle battery capacity), measures of full lifecycle emissions, or the number of zero emission miles traveled. The ideal set of metrics also should incentivize efficiency, which for ZEVs can vary even though all vehicles have zero tailpipe emissions. Task 2 evaluates the key goals that potential metrics should support and the relevance and practicality of various metrics.

3. *What will be the cost in California of the transition to a self-sustaining market, and how long will it take?*

   Building on work that has been undertaken nationally and internationally, this task will quantify to the extent possible the public or private investment needed to get through the proverbial “valley of death” before zero emission electric drive technologies can compete in the market without subsidies. Task 3 will address the magnitude and duration of needed policies under various scenarios. This task is currently in progress.

4. *Which complementary policies (e.g., infrastructure rollout, incentives) are needed to support a transition to an electrified vehicle fleet, and what is the appropriate framework for considering possible policy actions?*

   Task 4 identifies and recommends policies that most effectively support the necessary transition and that are applicable in the California context. The study also assesses the extent to which existing global policies will facilitate this transition, such as global private and public investments in research, development, and demonstration; manufacturing scale-up; and the need for California-specific investments in areas such as infrastructure.

5. *What can we learn from work under way elsewhere in the world?*

   Task 5 (forthcoming) reviews region-specific market niches, infrastructure challenges, and existing policies to identify lessons applicable to California and how they can best be applied in the California context. Although specific insights relevant to the previous tasks are included in those reports as appropriate, this task presents a comprehensive review of global policies. The selection of regions accounts for the targets, goals, and policies in place in each jurisdiction and the existence of market opportunities as evidenced by manufacturer vehicle introductions and interest.

Defining the Goal

This study is intended to identify and promote policies that support vehicle electrification, focusing on the California ZEV program. In light of the history of the ZEV program and its surrounding controversy, it is helpful to clearly and carefully define the overall goal of vehicle electrification policy. In ICCT's view, the goal is to foster a successful long-term transition to zero-carbon electric drive transportation. Framing the goal in this manner has several implications:

- It emphasizes the long-term nature of the required effort. Widespread deployment of a fundamentally different technology and the associated infrastructure will take decades to achieve under the best of circumstances.
- It acknowledges the broad scope of measures needed. Success will require not only mainstream deployment of vehicles and infrastructure but also substantial efforts to clean up the grid and foster renewable electricity and hydrogen production.
- Perhaps most important, "fostering a successful long-term transition" is not the same thing as "deploying as many ZEVs as possible as soon as possible." Deployment must be orderly and sustainable and must avoid the boom-and-bust cycles that have plagued many previous alternative fuel efforts.

Viewed in this light, the ZEV program is a piece of the puzzle but not the sole determinant of success or failure. This report and the companion ICCT reports on the other tasks seek to lay out recommendations for the ZEV program and related policies that will help chart a sustainable course.

The Task 1 Report

This document presents analysis and findings for Task 1, the review of technology status and its implications for policy. The purpose of this report is to review the current status of BEV and FCEV technology, then use the results of that review to provide insight into the scale of future requirements under the California ZEV program. It thus provides a policy-relevant updated compilation of recent work. ARB staff have asked for comment on the issues addressed herein, and this document is intended to assist staff in their deliberations.

THE CALIFORNIA ZEV PROGRAM

Because this study in large part is directed toward providing information to support the consideration of modifications to the ZEV program, a brief outline of the current program follows. The ZEV regulation was adopted in 1990 and has undergone significant periodic modifications since, most recently in 2008. In its current form, the program calls for increasing placement of ZEVs by manufacturers over successive 3-year phases. Although the regulation requires the placement of ZEVs, it is not a mandate for particular technologies but rather a technologically neutral performance standard under which a portion of the fleet must meet a tailpipe emission standard of 0 g/mi.

The ZEV program provides considerable flexibility to manufacturers, such that the actual number of vehicles required depends on the type of vehicle to be placed and various other factors. Table 1 shows the current requirements assuming that manufacturers place all Type II ZEVs (full-function BEVs with a range of 100–200 mi) or all Type V ZEVs (vehicles with a range of 300 mi and capable of fast refueling; in practice, FCEVs). Note that actual deployments will be lower than the numbers shown because of the use of previously earned ZEV credits.

Table 1. ZEV Percentage Requirements

Phase	Overall Percentage Requirement	"Pure ZEV" Percentage Requirement (excluding PZEVs and AT PZEVs)	Cumulative No. Vehicles (if Type II)	Cumulative No. Vehicles (if Type V)
I (2005–2008)	10	2	~4,000	250
II (2009–2011)	11	2.5	~3,500	~1,500
III (2012–2014)	12	3	~12,500	~7,500
IV (2015–2017)	14	4	~48,000	~20,500

ZEV = zero-emission vehicle; PZEV = partial zero-emission vehicle; AT PZEV = advanced technology partial zero-emission vehicle.

At a November 15, 2010, public workshop, the ARB staff presented its current approach regarding modifications to the program:

- *Phase IV (2015–2017):* Leave the current requirements in place without significant modification. Depending on the type of vehicle offered by manufacturers, this will require approximately 20,500 cumulative FCEVs or 48,000 cumulative BEVs with a range of 100 mi over the 3-year period.
- *Phase V (2018–2021):* An annual requirement of 1.5%, 2%, 3%, and 4% for 2018, 2019, 2020, and 2021, respectively (assuming that manufacturers take full

advantage of the ability to use transitional ZEVs (TZEVs)—which will primarily be PHEVs—to satisfy a portion of the requirement). Using ARB's estimates of projected sales and the types of vehicles likely to be deployed, this would require approximately 21,000 vehicles (excluding TZEVs) in 2018, increasing to approximately 59,000 in 2021.

- *Phase VI (2022–2025):* An annual requirement of 5%, 6%, 7%, and 8% for 2022, 2023, 2024, and 2025, respectively, again assuming full use of other options. Using ARB's estimates of projected sales and the types of vehicles likely to be deployed, this would require approximately 80,000 vehicles (excluding TZEVs) in 2022, increasing to approximately 120,000 in 2025.
- *2026 and beyond:* Transition to a fleet average requirement.

ARB staff has invited comment on the overall approach, the number of vehicles required in 2025, and the interim ramp-up to be required in 2018 through 2025. The focus of this ICCT paper (technology status and cost) primarily relates to issues regarding the required number of vehicles. ARB staff also asked for comment on ZEV credit factors. That topic is the subject of the ICCT Task 2 report on metrics.

CURRENT CONTEXT

This section provides an overview of some overarching trends and issues to provide a context for the consideration of vehicle electrification issues.

The California ZEV Program Is No Longer Alone

The California ZEV program is no longer the only governmental driver of progress in passenger vehicle electrification. Ten years ago, during the 2001 ZEV review, the vehicle target numbers set forth in the regulation essentially defined the number of such vehicles that would be produced worldwide. Today, things have changed dramatically. Many other jurisdictions are pushing vehicle electrification and have active programs under way. Here in the United States, federal and state incentives for auto manufacturers and parts suppliers (primarily oriented toward PHEVs) and infrastructure development, along with matching private funds, have reached approximately $10 billion.[1] The United Kingdom offers incentives of £5,000 per vehicle,[2] and Transport for London has committed to provide 25,000 charging points and procure 1,000 fleet vehicles by 2015.[3] France is offering vehicle incentives of €5,000 and a consortium of major industries has committed to order 50,000 vehicles.[4] China is making vehicle electrification a major policy focus, has

1 *Advanced technology to meet California's climate goals: Opportunities, barriers & policy solutions*. California ETAAC Advanced Technology Sub-Group focusing on clean transportation, energy efficiency and renewable energy and updating selected sections of the February 2008 ETAAC report. December 14, 2009, pp. 6–5. Available at: www.arb.ca.gov/cc/etaac/meetings/etaacadvancedtechnologyfinalreport12-14-09.pdf

2 www.autonews.com/apps/pbcs.dll/article?AID=/20100227/COPY/302279991/1193

3 ecogeek.org/component/content/article/3023

4 www.euractiv.com/en/climate-environment/france-awaits-clearer-eu-strategy-on-e-cars-news-464836?utm_source=EurActiv+Newsletter&utm_campaign=329ce9af9a-my_google_analytics_key&utm_medium=email

earmarked 100 billion yuan ($15 billion) over 10 years for research and development for new energy vehicles and components,[5] and has mounted more than 25 demonstration programs in major cities. Demonstrations, incentive programs, and related efforts are also under way in Germany, Sweden, Japan, Korea, Canada, and other countries.

Meanwhile, vehicle manufacturers are aggressively pursuing a variety of advanced technologies to secure their competitive position in the global marketplace. Manufacturers are responding to what they perceive as market opportunities, although in almost all cases, those markets are supported by government programs and regulatory requirements or the threat of regulation. Nissan has become the first large volume manufacturer to offer an electric vehicle to the public, and General Motors is beginning the rollout of the Volt PHEV. The Renault-Nissan Alliance has entered into partnerships with cities around the world to promote the installation of infrastructure. General Motors, Honda, Daimler, Hyundai and Toyota are sponsoring consumer tests of their latest FCEVs. BEV demonstrations are being sponsored by Ford, BMW, Volkswagen, Mitsubishi, Think, and others. New players such as Tesla are actively marketing vehicles. Thus, there is considerably more activity and investment on the part of manufacturers than in the past.

Finally, traditional tailpipe vehicle regulatory programs are no longer the only policies that push for reductions in motor vehicle emissions. They now are one part of a suite of policies to reduce motor vehicle criteria and GHG emissions on a variety of fronts. As ARB staff has emphasized, the ZEV program is deeply intertwined with the LEV III criteria pollutant and GHG regulations. However, the ZEV program also interacts with the Low Carbon Fuel Standard, the Renewable Energy Standard, and emerging state and federal climate policy.

This of course does not mean that the ZEV program is no longer important. It is still seen globally as a critical factor in electric vehicle deployment, and California can and should continue to play a leadership role, not the least because other markets alone are unlikely to achieve commercialization on a pace and at a price sufficient to achieve California's environmental and economic goals. The ZEV program connects technology development with public necessity, but the unprecedented scale of activity worldwide changes how we need to think about the ZEV program today compared with its early years.

Near-Term Needs Differ From Long-Term Needs

Policies to encourage vehicle electrification must be mindful of quite different near-term and long-term challenges. In the near term, the goal is commercialization through successful deployment of the first waves of vehicles and ramping up to larger production volumes. Because vehicle numbers are small, the emission reductions at this stage are relatively minor. From a policy standpoint, in the near term, the emphasis needs to be on encouraging ongoing technology development, establishing complementary policies that will encourage the deployment of electric drive vehicles, ensuring that

5 www.businessgreen.com/bg/news/1869822/china-produce-million-electric-cars-2020

the necessary infrastructure is provided in an efficient and cost-effective manner, and securing for California a significant share of the green jobs that will be created as new transportation technologies emerge. These are primarily institutional issues that will require active governmental leadership and participation.

In the long term, the focus is on emission reductions and energy security. To have a measurable impact, there must be large numbers of vehicles, and zero tailpipe emission vehicles need to be cost competitive with other power train technologies. Financial incentives sustained over the long term (e.g., from a feebate program or tax policy) can improve the competitive position of advanced technology vehicles, but there are limitations to the effectiveness and durability of targeted subsidies.

Targets and Technology Must Coincide

Although the global level of support for vehicle electrification is encouraging, significant obstacles must be overcome before any pure electric drive vehicle can compete with continually improving conventional power trains and achieve deployment volumes sufficient to make an environmental difference. The pace of clean vehicle deployment ultimately is driven first by technology status, then by cost and consumer demand, not by projections of the need for ultra-low emission vehicles. This has been one of the difficult lessons learned throughout the history of the ZEV program, as the targeted number of vehicles has had to be reduced in the face of slower-than-expected progress. Technology is progressing rapidly, but that does not change the fundamental dynamic of cost and demand.

The ZEV Program Needs to Support and Encourage Both BEVs and FCEVs

The two main contenders for pure vehicle electrification—BEVs and FCEVs —are in different stages of development and will have different deployment trajectories. BEVs are coming to the market now in various forms, but given current battery capabilities, the initial passenger vehicle deployments are primarily PHEVs; small, urban pure electric vehicles with limited range; and high-end performance vehicles. FCEVs are in an earlier stage of development and more expensive in the near term than short-range BEVs, but they have the potential to ultimately be attractive to a larger segment of the driving public. The California ZEV program originally emphasized BEVs, but shifted over time to include and then provide additional credit for fuel cells on the basis of indications of manufacturer interest in pursuing fuel cell technology. Currently, manufacturers have different views on which technology holds the greatest promise for satisfying customer needs, and the ZEV crediting system must encourage a portfolio of technologies. Many experts believe that there will ultimately be a “continuum” of drivetrains in which small, short-range vehicles use batteries and larger, longer-range vehicles use fuel cells.[6] These issues are addressed in more detail in the Task 2 report on metrics.

6 See for example *A portfolio of power-trains for Europe: A fact-based analysis. The role of battery electric vehicles, plug-in hybrids and fuel cell electric vehicles*. Available at: www.zeroemissionvehicles.eu/uploads/Power_trains_for_Europe.pdf.

TECHNOLOGY COST, STATUS, AND PROJECTIONS

Battery, fuel cell, and vehicle manufacturers are working vigorously to improve performance, reliability, and driveability on a variety of fronts. For BEVs, the primary technical challenges involve safety, reliability/manufacturability, durability, and cost.[7] For FCEVs, the focus is on durability and cost,[8] as well as providing hydrogen fuel in a cost-effective manner during the low-volume startup period. Although all of these technology issues are important, this report focuses on cost.

ICCT has reviewed the most recent literature regarding the current and projected cost of FCEVs and BEVs and the related infrastructure. The cost of producing advanced technology vehicles is expected to decline as the underlying technology improves, as design and manufacturing experience is gained from increased cumulative production, and as economies of scale are gained from increased annual production volume.[9]

Although electric drive vehicles will have a cost premium for the foreseeable future, they also have some operating cost savings. Avoided maintenance costs relative to internal combustion engine vehicles should total approximately $2,000 (undiscounted) over the first 8 years[10] for BEVs and FCEVs. Annual fuel cost savings for a BEV driven a low level of 7,000 mi annually would be approximately $500 compared with an average nonhybrid internal combustion engine vehicle. Fuel cost savings per year for a mileage of 14,000 (the average for conventional vehicles) would be approximately $1,000.[11] FCEVs also have the potential for fuel cost savings when deployed at commercial scale, largely depending on future hydrogen production and distribution pathways and in part on levels of technology advancement. The cost of FCEV hydrogen fueling infrastructure before full commercialization is addressed further in the ICCT Task 4 report on complementary policies.

FCEVs

Authoritative estimates of FCEV costs were performed in 2008. They include the following:

- A study by Greene and Leiby[12] at Oak Ridge National Laboratory

7 Anderman, M. (2010). Feedback on ARB's Zero-Emission Vehicle Staff Technical Report of 11/25/2009 including Attachment A: Status of EV Technology Commercialization, January 6, 2010, p. 2. Available at: www.arb.ca.gov/msprog/zevprog/2009zevreview/anderman_review.pdf

8 California Air Resources Board. (2009). *White paper: Summary of staff's preliminary assessment of the need for revisions to the zero emission vehicle regulation.* Available at: www.arb.ca.gov/msprog/zevprog/2009zevreview/zevwhitepaper.pdf

9 To be most useful, cost projections should specify assumptions regarding these factors. More often than not, however, one or the other of these parameters is not noted. We have attempted to put the various estimates on a comparable basis, but this necessarily involved some judgment on our part.

10 *Comparing the Benefits and Impacts of Hybrid Electric Vehicle Options*. EPRI Report 1000349 (July 2001 updated to 2010 prices based on CPI data). Available at: www.advancedenergy.org/transportation/phesb/pdfs/EPRI1-0.pdf

11 Assumes 30 mpg real-world fuel economy for a conventional vehicle, 34 kWh/100 mi for a Nissan Leaf, gasoline price $3/gal, electricity price $0.30 per kWh on peak, $0.10 per kWh mid-peak and $0.05 off-peak, with charging 10% peak, 10% mid peak, and 80% off peak.

12 Greene, D. L., Leiby, P. N., James, B., Perez, J., Melendez, M., Milbrandt, A., et al. (2008). *Analysis of the transition to hydrogen fuel cell vehicles and the potential hydrogen energy infrastructure requirements.* ONRL/TM-2008/30. Oak Ridge, TN: Oak Ridge National Laboratory. Available at: http://cta.ornl.gov/cta/Publications/Reports/ORNL_TM_2008_30.pdf

- The National Research Council (NRC)[13] study for the U.S. Department of Energy (DOE)
- A Massachusetts Institute of Technology (MIT) study[14] estimating the "built-out cost" of FCEVs and BEVs
- A peer-reviewed estimate[15] by Thomas for the National Hydrogen Association

More recently, a European consortium of companies and organizations prepared a *Power-Trains for Europe* study of alternative power trains that could meet long-term GHG reduction goals, with consulting support from McKinsey & Company.[16]

Table 2 summarizes the FCEV cost estimates provided by the studies listed here, aas well as estimates made by Hyundai[17] and by Sig Gronich[18], the former head of DOE's hydrogen program.

Table 2. Fuel Cell Vehicle Cost Estimates ($)

Analyst	2010	2012	2015	2017	2020	2023	2026	"Built out"
NRC[13]			75,000	50,000	32,000	30,000	27,000	
Greene[12]		350,000	80,000	50,000			30,000	
MIT[14]								26,600
Thomas[15]	171,000	130,000	80,023	65,000	45,000	33,765	27,346	
Hyundai[17]					50,000			
Powertrains for Europe (McKinsey)[6]					*34,750			**32,000
Gronich[18]			77,000					

*€25,700 for C/D segment vehicle
**€23,700 for C/D segment vehicle in 2030

C segment vehicle = European Union small car, D segment vehicle = European Union large car; NRC = National Research Council; MIT = Massachusetts Institute of Technology.

13 Committee on Assessment of Resource Needs for Fuel Cell and Hydrogen Technologies. (2008). *Transitions to alternative transportation technologies—A focus on hydrogen*. Washington, DC: National Research Council of the National Academies. Available at: www.nap.edu/catalog/12222.html

14 Bandivadekar, A., Bodek, K., Cheah, L., Evans, C., Groode, T., Heywood, J., et al. (2008). *On the road in 2035: Reducing transportation's petroleum consumption and GHG emissions.* Cambridge: Massachusetts Institute of Technology. Available at: http://web.mit.edu/sloan-auto-lab/research/beforeh2/otr2035/On%20the%20Road%20in%202035_MIT_July%202008.pdf

15 *The energy evolution: An analysis of alternative vehicles and fuels to 2100.* (2009). Washington, DC: National Hydrogen Association. Available at: www.hydrogenassociation.org/general/taskForce/evolutionReport.pdf

16 *A portfolio of power-trains for Europe,* op. cit.

17 www.autocar.co.uk/News/NewsArticle/AllCars/250265/

18 Gronich, S. *Are plug-in/battery electric vehicles more market ready than hydrogen fuel cell vehicles?* Paper presented at the National Hydrogen Association Conference, Sacremento, CA, 5 May 2010.

To provide another perspective on these estimates, we developed a rough estimate of the cost of a FCEV that could be built by retrofitting a 2010 base Prius with an 80 kW[19] fuel cell system and hydrogen storage tank. Our estimate results in a rough approximation of the cost of a comparable FCEV before any engineering and assembly costs are added. System costs include a profit margin for suppliers in most cases. As shown in Table 3, this exercise suggests that FCEVs could achieve a cost below $50,000 by 2015, even assuming low-volume production of approximately 1,000 vehicles per manufacturer. In the second case, we used an Argonne National Laboratory estimate of the cost of an electric vehicle glider in 2015.[20] This methodology yields more optimistic results than the Greene ($80,000)[21] and NRC ($75,000)[22] estimates for 2015, but given the progress made in the past 2 years, perhaps the optimism is justified. Note that our estimates do not assume that DOE's cost targets would be met.

Table 3. Low Volume (~1,000) Fuel Cell Vehicle Cost ($)

	2010				2015			
	Vehicle	Fuel Cell	Tank	Total	Vehicle or Glider	Fuel Cell	Tank	Total
Prius	21,000	20,388	3,000	41,388	21,000	14,733	3,000	36,333
ANL Electric Vehicle Glider[20]	N/A				10,799	14,733	3,000	28,532

Note: Tank assumes 6-kg tank, 39.4 kWh per kg at 0.08 kWh per dollar, cited by the tank manufacturer, Quantum, in 2009.23 Department of Energy target is 0.25 kWh per dollar. ANL = Argonne National Laboratory.

The Prius calculation used the published price of a base Prius and assumed no cost reduction between 2010 and 2015 for any components except for the fuel cell system. The FCEV tank costs were derived from an estimate given by Quantum, a tank manufacturer, in 2009.[23] The cost of a fuel cell system was based on low volume (~1,000 units) estimates presented in 2009 by Directed Technologies Inc. (DTI).[24] DTI's cost generally includes markup and all associated hardware other than the fuel storage component. Details of the DTI estimates are provided in Table 4. To put these estimates in perspective, DTI suggests that the low-volume cost of an 80 kW fuel cell is comparable to the current cost of the Leaf's 24 kWh battery pack. According to Tesla CEO Elon Musk, the cost of the Tesla's 53 kWh battery pack is $36,000.[25]

19 In practice, one likely could reduce the size of the fuel cell system in such a vehicle, at a cost savings.

20 *Multi-path transportation futures study: Vehicle characterization and scenario analyses*. (2009). ANL/ESD/09-5. Argonne, IL: Argonne National Laboratory; p. 53.

21 Greene et al., op. cit.

22 Committee on Assessment of Resource Needs for Fuel Cell and Hydrogen Technologies, op. cit.

23 Liu, C. *Low-Cost High-Efficiency High-Pressure H2 Storage*. Paper presented by Quantum Fuel Systems Technologies Worldwide Inc. DOE 2009 Annual Merit Review, 20 May 2009. Available at: http://www.hydrogen.energy.gov/pdfs/review09/stp_04_liu.pdf

24 *The energy evolution: An analysis of alternative vehicles and fuels to 2100*, op. cit.

25 http://blogs.edmunds.com/greencaradvisor/2009/02/tesla-battery-pack-replacement-would-be-36000-today-musk-says.html

Table 4. Cost-Volume Estimates for Fuel Cell Stack and System ($)

		1,000 units	30,000 units	80,000 units	130,000 units	500,000 units
Stack	2008	12,472	4,596	4,007	3,663	3,014
	2010	10,968	3,821	3,104	2,837	2,353
	2015	5,301	1,735	1,376	1,242	1,002
System	2008	20,388	10,001	8,033	7,342	6,005
	2010	17,317	8,312	6,595	5,991	4,943
	2015	14,733	6,583	5,236	4,779	4,047
Per kW	2010	216	104	80	75	62
	2015	184	82	65	60	51

Note: National Research Council (NRC) base for internal combustion engine (ICE): $54; NRC high efficiency for ICE: $64; 80 kW system (stack, balance of plant assembly, and testing). Includes manufacturer markup, where appropriate.

Several recent developments and announced goals suggest that the auto industry is moving more quickly down the cost curve than was thought to be possible in 2007 when the data for the 2008 studies were gathered:

- Press reports stated that Toyota has cut the cost of making fuel-cell vehicles by about 90% since earlier estimates in the mid-2000s that ran as high as $1 million per vehicle.[26] The Japanese carmaker stated that it would need to further reduce current expenses by about half before starting retail sales.
- In September 2009, Daimler, Ford, GM, Honda, Hyundai/Kia, Toyota, and the Renault-Nissan Alliance issued a joint letter of understanding stating, in part,

> Based on current knowledge and subject to a variety of prerequisites and conditions, the signing OEMs strongly anticipate that from 2015 onwards a quite significant number of fuel cell vehicles could be commercialised. This number is aimed at a few hundred thousand (100,000) units over life cycle on a worldwide basis. All OEMs involved will implement their own specific production and commercial strategies and timelines, and, as a consequence, depending on various influencing factors, the commercialisation of fuel cell vehicles may occur earlier . . ..[27]

More recently, Hyundai announced that a production version of a FCEV will go on sale in 2012.[28]

26 www.bloomberg.com/apps/news?pid=20601080&sid=al_cyfcmTdls
27 www.h2carblog.com/wp-content/uploads/2009/10/Letter-of-Understanding.pdf
28 www.allcarselectric.com/blog/1048608_report-hyundai-fuel-cell-electric-vehicle-coming-in-2012

- General Motors' new fuel-cell stack uses nearly two-thirds less platinum (30 g compared with 80 g) than the stack in the current generation of Equinox vehicles. General Motors believes it can achieve platinum loadings of 10 g, equivalent to today's auto catalytic converters, by 2020.
- Japanese automakers announced at the 2010 Fuel Cell Expo in Tokyo a program designed to deploy 2 million FCEVs in Japan by 2025, at which point the industry estimates FCEVs would be fully competitive.

Significant challenges remain, however, before the anticipated cost reductions will be achieved. In his recent review of the ARB staff ZEV technology assessment, the noted battery expert Dr. Anderman noted that

> during my visits it also became apparent that several (but not all) car companies had redeployed technical staff from fuel-cell development to work on Li-Ion batteries. In addition, some of these companies also mentioned that technology investment in the FC-component supply chain is in decline. These two changes combine to reduce the likelihood of the fast progress in fuel-cell technology that was expected a few years ago.[29]

In light of the progress reported, however, this view may be unduly pessimistic.

BEVs

Many recent evaluations of battery cost have focused on lithium-ion chemistry as the most attractive candidate for commercialization:

- The 2007 report of the ARB Independent Expert Panel[30]
- The 2009 ARB staff report[31] and Technical Support Document[32]
- Comments by Advanced Automotive Batteries on the 2009 ARB staff report[33]
- An MIT study[34] estimating the "built out cost" of FCEVs and BEVs
- Reports by the Boston Consulting Group,[35] Deutsche Bank,[36],[37] Pike Research,[38] the Rocky Mountain Institute[39] and the Electrification Coalition[40]

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29 Anderman, op. cit.

30 Kalhammer, F. R., Kopf, B. M., Swan, D. H., Roan, V. P., Walsh, M. P. *Status and prospects for zero emissions vehicle technology: Report of the ARB Independent Expert Panel.* (2007). Sacramento: California Air Resources Board. Available at: www.arb.ca.gov/msprog/zevprog/zevreview/zev_panel_report.pdf

31 California Air Resources Board. *White paper: Summary of staff's preliminary assessment of the need for revisions to the zero emission vehicle regulation,* op. cit.

32 California Air Resources Board. *White paper: Summary of staff's preliminary assessment of the need for revisions to the zero emission vehicle regulation*, Attachment A, Status of ZEV Technology Commercialization, (Technical Support Document). Available at: www.arb.ca.gov/msprog/zevprog/2009zevreview/attachment_a_tsd.pdf

33 Anderman, op. cit.

34 Bandivadekar, et al., op. cit.

35 Boston Consulting Group. *Batteries for electric cars: Challenges, opportunities and the outlook to 2020*. (2010). Available at: www.bcg.com/documents/file36615.pdf

36 Lache, R., Galves, D., Nolan, P. (2009). *Electric cars: Plugged in 2. A mega-theme gains momentum.* Frankfurt, Germany: Deutsche Bank Securities, Inc.. Available at: www.fullermoney.com/content/2009-11-03/ElectricCarsPluggedIn2.pdf

37 Lache, R., Galves, D., Nolan, P. (2010). *Vehicle electrification: More rapid growth; steeper price declines for batteries*. Frankfurt, Germany: Deutsche Bank Securities, Inc. Available at: http://gm-volt.com/files/DB_EV_Growth.pdf

38 Gargner, J., & Wheelock, C. (2009). *Electric vehicles: 10 predictions for 2010.* Boulder, CO: Pike Research. Available at: www.pikeresearch.com/research/electric-vehicles-10-predictions-for-2010

39 Anderson, D. (2008). *Status and trends in the HEV/PHEV/EV battery industry*. Snowmass, CO: Rocky Mountain Institute.

40 Electrification Coalition. (2009). *Electrification roadmap, revolutionizing transportation and achieving energy security*. Washington, DC. Available at http://www.electrificationcoalition.org/electrification-roadmap-download.php

- The *Power-Trains for Europe* study of alternative power trains that could meet long-term GHG reduction goals[41]
- NRC[42] study of PHEVs for DOE
- The Interim Joint Technical Assessment Report (TAR) on light-duty GHG emissions standards prepared by the U.S. Environmental Protection Agency, National Highway Traffic Safety Administration, and the California ARB[43]; battery costs in this assessment are based on work done by the Argonne National Laboratory[44]
- DOE cost projections provided in its summary of Recovery Act investments[45]
- A TIAX LLC cost assessment for PHEV batteries performed for DOE[46]

Table 5 lists the conclusions of the various studies in terms of the battery cost per kWh, at the battery pack level, for BEVs. Table 5 also shows several unpublished estimates provided by Chinese battery manufacturers during June 2010 discussions. Table 6 provides the published information for PHEV batteries. The latter require more power per unit weight and tend to be more expensive on a kWh basis. To provide context for these cost numbers, note that the plug-in Prius will have a 5.2 kWh battery pack to travel 14.5 mi in all-electric mode (on the Japanese test cycle), whereas the Nissan Leaf will have a 24 kWh battery pack.

41 *A portfolio of power-trains for Europe*, op. cit., p. 60.

42 Committee on Assessment of Resource Needs for Fuel Cell and Hydrogen Technologies, op. cit.

43 Office of Transportation and Air Quality, U.S. Environmental Protection Agency; Office of International Policy, Fuel Economy, and Consumer Programs, National Highway Traffic Safety Administration, U.S. Department of Transportation; California Air Resources Board, California Environmental Protection Agency. *Interim joint technical assessment report: Light-duty vehicle greenhouse gas emission standards and corporate average fuel economy standards for model years 2017–2025*. (2010). Available at: www.nhtsa.gov/staticfiles/rulemaking/pdf/cafe/2017+CAFE-GHG_Interim_TAR2.pdf

44 See (1) Nelson, P. A., Santini, D. J., & Barne, J. (2009). *Factors Determining the Manufacturing Costs of Lithium-Ion Batteries for PHEVs*. Paper presented at the 24th International Electric Vehicle Symposium (EVS-24), Stavanger, Norway, 2009. Available at: www.cars21.com/files/papers/Nelson-Santini-Barnes-paper.pdf, and (2) Santini, D. J., Gallagher, K. G., & Nelson, P. A. *Modeling of manufacturing costs of lithium-ion batteries for HEVs, PHEVs, and EVs*. (2010).Paper presented at the 25th International Electric Vehicle Symposium (EVS-25), Shenzhen, China.

45 Derived from figures in Department of Energy, *The Recovery Act: Transforming America's Transportation Sector, Batteries and Electric Vehicles*, Wednesday, July 14, 2010.

46 Barnett, B., Rempel, J., Ofer, D., Oh, B., Sriramulu, S., Sinha, J., Hastbacka, M., & McCoy, C. PHEV Battery Cost Assessment, DOE Annual Merit Review. (2010). Available at: www1.eere.energy.gov/vehiclesandfuels/pdfs/merit_review_2010/electrochemical_storage/es001_barnett_2010_o.pdf

Table 5. Battery Cost Estimates—BEVs ($/kWh nominal capacity)

Analyst	2010	2012	2015	2016	2020	2025	Built Out
2007 ARB Panel[30]			425–525		300–350		
Advanced Automotive Batteries[33]			500–700		375–500		
MIT[34]							200–250
Boston Consulting Group[35]	990–1220				360–440		
Deutsche Bank[36,37]	650	mid-400			325		
Pike Research[38]	940	680	470				
Electrification Coalition[40]	600		550				225
Powertrains for Europe (McKinsey)**[41]	1177		618		405		
Joint TAR[43]						140, 150, 160***	
Argonne National Lab[44]					150–200		
OEMs per TAR					300–400	250–300	
DOE Recovery Act	1,000*	500*		300	150		
Chinese manufacturers	500; 730		295; 500		150; 365		

*DOE date for $1,000/kWh is 2009 and for $500/kWh is end of 2013

**€871 for 2010, €457 for 2015, €300 for 2020

***$140 for EV 150, $150 for EV 100, $160 for EV 75

ARB = Air Resources Board; MIT = Massachusetts Institute of Technology; TAR = Technical Assessment Report; OEM = original equipment manufacturer; DOE = U.S. Department of Energy.

Table 6. Battery Cost Estimates—PHEVs ($/kWh-nominal capacity)

Analyst	2010	2012	2015	2017	2020	2025	Built Out
NRC*	875				560		
Rocky Mountain Institute[39]	600–700				300–350		
MIT							270, 420**
Deutsche Bank[36,37]	900–1,000		500–600	400–500			
TIAX					211–398		
Joint TAR[43]						180, 250***	
Argonne National Lab[44]					200–250, 300–400****		
OEMs per ARB[31,32]	800–1,000						

*NRC estimate is $1,750 per kWh of "usable" capacity, which is assumed to be 50% of nominal capacity. This estimate increases battery cost by a factor of two compared with other estimates.

**$270 for PHEV 60, $420 for PHEV 10

***$180 for PHEV 40, $250 for PHEV 20

****200–250 for PHEV 40, $300-400 for PHEV 10

NRC = National Research Council; MIT = Massachusetts Institute of Technology; TAR = Technical Assessment Report; OEM = original equipment manufacturer; ARB = Air Resources Board; PHEV = plug-in electric vehicle.

Estimates of current costs vary considerably, as do the anticipated cost reduction trajectories. For example, Deutsche Bank concluded in November 2009 that

> With additional volume, and with innovations currently under development, we believe the industry already has visibility on a 25% reduction from this level [$650 per kWh] by 2015 (note that some industry players are already quoting prices below $500 kWh today for energy batteries). By 2020, the industry anticipates a 50% reduction in prices for energy batteries, to approximately $325/kWh.[47]

A March 2010 update further noted that,

> Battery costs appear to be coming down faster than we expected... Several automakers have told us that they have already seen bids in the mid-$400/kWh

47 Lache et al., Electric Cars, op. cit. p. 45.

> range for battery packs for large-volume contracts in the 2011/2012 time-period (we expected $490-$500/kWh by 2015 and $325/kWh by 2020).[48]

The Boston Consulting Group has a higher initial estimate but sees more dramatic cost reductions:

> Our analysis suggests that from 2009 to 2020, the price that OEMs pay for NCA batteries will decrease by 60 to 65 percent. So a nominal-capacity 15-kWh NCA battery pack that currently costs $990 to $1,220 per kWh will cost $360 to $440 per kWh in 2020.[49]

Meanwhile, the NRC is less optimistic regarding potential cost reductions for PHEV batteries:

> Lithium-ion battery technology has been developing rapidly, especially at the cell level, but costs are still high, and the potential for dramatic reductions appears limited . . .. Costs are expected to decline by about 35 percent by 2020 but more slowly thereafter.[50]

The NRC results have been criticized as overstating the capacity and cost of batteries needed for PHEVs.[51,52]

Cost projections for rapidly evolving technologies are by their nature uncertain. In addition, details of the methodology used can vary in ways that affect the results. A 2010 paper by James Miller of Argonne National Laboratory[53] provided a thorough and useful comparison of several of these estimates, "taking particular note of the varying assumptions used regarding such important factors as power-to-energy ratio, battery chemistry, production scale, rated capacity vs. useable capacity, and beginning-of-life vs. end-of-life." The author concluded that:

> high-power battery at low production volume will have a drastically different cost per kWh compared with a high-energy battery at high-volume production. Furthermore, other factors that are, or are not, included in the costs as reported, such as marketing, warranty, and profit, can have a large impact of reported costs; the manner in which these factors are treated can account for large differences between a manufacturer's production cost and the battery selling price.

Dr. Anderman from Advanced Automotive Batteries noted:

> We focused our study on data from the major materials, cell, and pack producers and avoided projections from less experienced companies. This may explain the higher pricing in comparison with the [California ARB] Panel study. Also, we and our information sources priced in what we believed will be necessary to meet the most important criteria for commercialization, namely safety, reliability, manufacturability, and durability.[54]

48 Lache et al., Vehicle Electrification, op. cit. p. 1.
49 Boston Consulting Group, op. cit. p. 7.
50 Committee on Assessment of Resource Needs for Fuel Cell and Hydrogen Technologies,, op. cit. p. 83.
51 www.allcarselectric.com/blog/1042471_electric-drive-director-duvall-confirms-nrc-reports-overstated-cost-of-plug-ins-and-batteries
52 www.electrificationcoalition.org/news-response-to-nrc.php
53 Miller, J. F. (2010). Analysis of current and projected battery manufacturing costs for electric, hybrid, and plug-in hybrid electric vehicles, p.1. Paper presented at EVS 25, Shenzhen, China.
54 Anderman, op. cit., p. 3.

Some analysts, such as Deutsche Bank, look to cost trends for consumer (e.g., laptop batteries) as a guide, saying, for example:

> At the same scale, battery manufacturers see no reason why the prices of Advanced Automotive Battery energy cells would be any higher than commercially available lithium cobalt oxide cells used in laptops. For reference, our research suggests that these batteries sold for $2.00/wh in 1995. Today they are selling for $0.24–$0.28/wh ($240-$280 per kWh). Including the cost of electronics, cooling/heating, fasteners, and other components of the pack, we believe that the overall cost of an EV battery should decline below $400 per kWh. Although the automotive manufacturing process may be more stringent (requires overhead for advanced product quality planning), and it requires somewhat more sophisticated additives, the overall material cost is lower—the raw materials used in an iron phosphate based lithium ion battery only cost $15 per kilogram, compared with $35-$45 for a cobalt oxide battery.[55]

Dr. Anderman, conversely, argued against extrapolating from the experience of consumer batteries because "there are no data in the public domain to project their durability and reliability in a vehicle battery."[56]

The NRC analysis indicated that lithium-ion battery technology is relatively mature, which then limits the potential for learning curve cost reductions. (ICCT noted, however, that cells for automotive use must meet far more demanding conditions, and entirely new chemistries are being developed. Thus, costs are high because these are new designs and dramatic reductions are still possible in the future.)

On balance, ICCT believes that it is advisable to take a conservative view of future fuel cell and battery progress as it relates to pure electric vehicle deployment, as exemplified in Dr. Anderman's work. Difficult challenges must be overcome, and these advanced technologies are competing with ever-improving conventional and hybrid electric vehicles. One of the lessons of the history of the ZEV program is that anticipated progress that would enable widespread pure electric vehicle deployment did not materialize as expected.

ZEV Rollout Projections and Commercialization Potential

Many researchers have studied the commercialization potential and the possible deployment trajectory of advanced vehicles. Although such study is highly uncertain, it can provide some insight into future production volumes and hence the likelihood of achieving the volume-based cost reductions noted earlier. ARB staff and others have also developed scenarios outlining how quickly ZEVs need to penetrate the vehicle fleet to support the achievement of an economywide 80% reduction in GHG emissions by 2050. This section summarizes the available analyses and then discusses their implications for ZEV policy.

55 Lache et al., *Electric Cars*, op. cit., p. 45.
56 Anderman, op. cit., p. 3.

Not surprisingly, various parties differ significantly in their views of commercialization potential. The *Power-Trains for Europe* study concluded that,

> After 2025, total costs associated over the lifetime of the electric vehicles (including the purchase price, fuel cost and maintenance cost) converge. They all become viable alternatives to traditional internal combustion engines. Together with tax incentives, BEVs and FCEVs could be cost-competitive with traditional internal combustion engines as early as 2020.[57]

This study does not discount future costs,[58] which will tend to favor total cost of ownership calculations for advanced power trains (which have higher upfront costs but lower operating costs because of their greater efficiency) versus conventional internal combustion engine vehicles (which have lower upfront costs but higher operating costs).

Deutsche Bank concluded that "by 2020, we expect HEVs and PHEVs/EVs to each represent 11%–12% of U.S. market sales (total of 23%),"[59] while Anderman maintained "it is very unlikely that either FC [fuel cell] vehicles or battery electric vehicles could be competitive in the mass market before 2020, or probably even 2025."[60] Most pessimistically, the NRC stated, "PHEV-40s are unlikely to achieve cost-effectiveness before 2040 at gasoline prices below $4.00 per gallon, but PHEV-10s may get there before 2030 . . .. [I]t is likely to be several decades before lifetime fuel savings start to balance the higher first cost of the vehicles."[61] Meanwhile, some manufacturers are considerably more bullish. For example, Nissan reported that as of September 23, 2010, it had reached its 2010 goal of 20,000 preorders for the Leaf and stopped taking reservations.[62] As reported by Reuters,

> Mark Perry, Nissan's North America director of product planning and strategy, told Reuters on the sidelines of an industry conference 'We are making money at the price that we announced,' Perry said. 'We priced the car to be affordable. We priced it for mass adoption.'[63]

The 2007 ARB ZEV Expert Panel report[64] set out the panel's judgment as to when various technologies could be expected to attain precommercial (thousands per year), low-volume commercial (tens of thousands per year) and mass commercial (hundreds of thousands per year) production volume. Reproduced as Figure 1, the report's graphic shows BEVs reaching low-volume commercialization in 2015, and FCEVs reaching that point in 2020. Although this report is now somewhat dated, its fundamental conclusions are echoed by more recent work.

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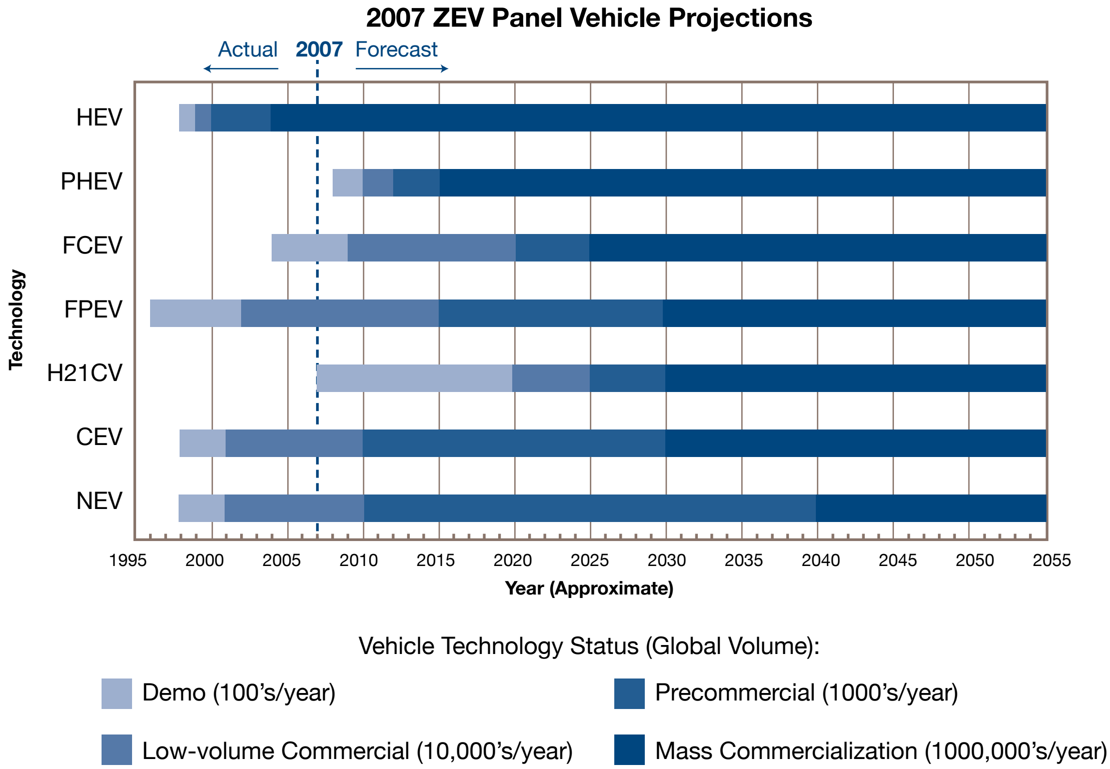
57 *A portfolio of power-trains for Europe*, op. cit., p. 3
58 *A portfolio of power-trains for Europe*, op. cit., p. 18.
59 Lache et al.,*Electric Vehicles*, op. cit. p. 14.
60 Anderman, op. cit., p. 4.
61 Committee on Assessment of Resource Needs for Fuel Cell and Hydrogen Technologies,, op. cit., p. 83.
62 www.autoblog.com/2010/09/24/report-nissan-reaches-20-000-leaf-pre-orders-will-stop-taking/
63 www.reuters.com/article/idUSTRE63T06Q20100430
64 Kalhammer, et al., op. cit.

Figure 1. Estimated ZEV Commercialization Timing

Projected Achievement of Global Volumes



HEV = hybrid electric vehicles; PHEV = plug-in hybrid electric vehicles; FCEV = fuel cell electric vehicles; FPBEV = full performance battery electric vehicles; H2ICV = hydrogen internal combustion vehicles; CEV = city electric vehicles; NEV = neighborhood electric vehicles.

To provide a more detailed review of current thinking regarding vehicle rollout, the following subsections summarize estimates made from five different perspectives:

- Manufacturer vehicle production plans
- Analyst vehicle sales projections
- Analyst customer demand projections
- Survey results
- Governmental targets and goals

This is followed by an ICCT analysis focused on the 2015–2020 timeframe that attempts to "bracket" likely vehicle deployment, drawing on several different views of the issue. The section concludes with a discussion of the near-term deployment implications of trying to reach long-term goals, other factors that affect deployment estimates, and some caveats regarding customer demand.

The focus of this report is on BEVs and FCEVs, but substantial deployment of PHEVs will also help support battery commercialization.

Manufacturer Vehicle Production Plans

The NRDC recently released an assessment of automakers' ability to comply with the California ZEV mandate based on announced production plans.[65] According to the report, its estimates are based on "information from company reports, media reports, consulting reports, capital investments, expert judgment, and forecasting tools."[66] The report concluded that planned deployment of pure electric vehicles (BEVs and FCEVs) in the United States in 2015 will be approximately 227,000 vehicles. A similar analysis by Nomura Research Institute, Ltd., found that global automaker electric vehicle production plans for 2015 add up to approximately 900,000 vehicles, with the majority being Renault/Nissan electric vehicles.[67] Given that the Deutsche Bank[68] estimate of 2015 electric vehicle deployment reported here shows the United States as accounting for approximately 17% of the global total, the NRDC and Nomura Research estimates are reasonably consistent.

Several manufacturers have stated their own targets for future deployment. Carlos Ghosn, CEO of Renault and Nissan, predicted that by 2020, electric vehicles will account for 10% of their sales.[69] Volkswagen has announced a goal of 3% of its sales in 2018 being electric vehicles.[70] Along the same lines, as previously noted, many fuel cell manufacturers have stated their expectation for placements in the hundreds of thousands beginning in 2015 and their intent to market a commercial FCEV in Japan, Korea, Europe, and one U.S. market.

Analyst Vehicle Sales Projections

Several analysts and consulting firms have prepared estimates of future electric vehicle penetration and battery production. Most are focused on 2020, but Table 7 shows 2015 estimates for combined BEV and PHEV production from Deutsche Bank.[71] The 2015 estimate for the United States by NRDC is included for comparison purposes, as is an estimate prepared by J.D. Power[72] for BEVs only.

65 Mui, S., & Baum, A. (2010). *The zero emission vehicle program: An analysis of industry's ability to meet the standards*. Washington, DC: Natural Resources Defense Council. Available at: http://docs.nrdc.org/energy/files/ene_10070701a.pdf

66 Ibid, p. 7.

67 Kazama, T. (2010). The outlook of automotive lithium ion battery market. Paper presented at Advanced Automotive Battery Conference, Orlando, FL.

68 Lache et al., *Electric Vehicles*, op. cit.

69 www.cnbc.com/id/33907442/Ghosn_s_Bet_10_of_World_Will_Drive_EV_s_in_10_Years

70 www.treehugger.com/files/2010/03/volkswagen-plans-sell-300000-electric-cars-year-2018.php

71 Lache et al., *Electric Vehicles*, op. cit., p. 61.

72 J.D. Power and Associates. (2010). *Drive green 2020: More hope than reality? A Special Report by J.D. Power and Associates*. New York: McGraw-Hill. Available at: http://businesscenter.jdpower.com/JDPAContent/CorpComm/pdfs/DriveGreen2020_102610.pdf

Table 7. Estimated 2015 Battery Electric Vehicle (BEV) and Plug-In Hybrid Electric Vehicle (PHEV) Annual Deployment (numbers in thousands)

	United States	European Union	Japan	China	Other	Total
Deutsche Bank[74]	127	160	45	348	61	742
Natural Resources Defense Council[65]	227	—	—	—	—	—
J. D. Power[76] (BEV only)	88	338	47	130		640

Looking further into the future, Figure 2 shows estimates of pure electric vehicle deployment in 2020 for major auto markets as prepared by Roland Berger,[73] Deutsche Bank,[74] the Boston Consulting Group,[75]and J. D. Power,[76] as well as the reported global penetration estimate from a recent study by Advanced Automotive Batteries (a region-by-region breakdown was not available).[77] To illustrate what these projections mean in terms of number of vehicles, the circled numbers in the figure show the number of vehicles implied by the Deutsche Bank percentage estimates for each region.

As was the case with the battery cost estimates discussed earlier, Dr. Anderman (Advanced Automotive Batteries) is notably less optimistic than the other analysts for both 2015 and 2020. The J.D. Power estimates are markedly lower for the United States but similar for the other jurisdictions.

73 *Powertrain 2020: The Future Drives Electric*. (2009). Munich, Germany: Roland Berger Strategy Consultants.

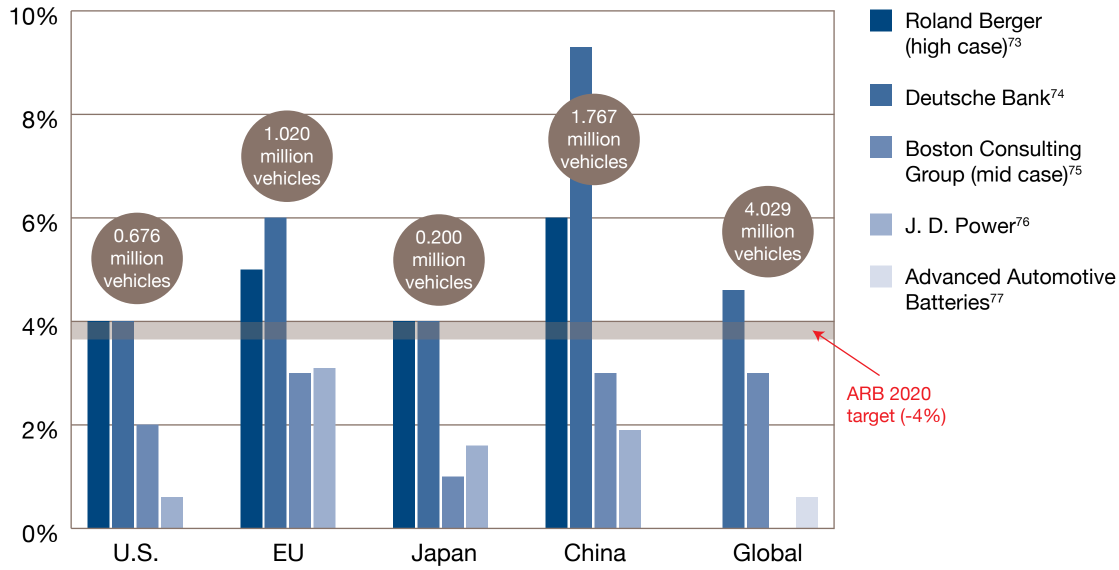
74 Lache et al., *Electric Vehicles*, op. cit., p. 61.

75 Boston Consulting Group. *The comeback of the electric car: How real, how soon, and what must happen next*. p. 7. Available at: www.bcg.com/documents/file15404.pdf

76 J.D. Power and Associates, op. cit.

77 www.greencarcongress.com/2010/04/aab-20100429.html

Figure 2. Projected BEV Penetration Rates, in 2020 (Percentage of Annual Sales)



Note: Circles represent total vehicle sales times projected Deutsche Bank BEV market percentage.

For comparison purposes, Figure 2 also shows the 2020 percentage target outlined by ARB staff at the November 15, 2010, workshop (nominally 4%). Electric vehicle sales rates in California are commonly expected to exceed those in other areas of the United States, because of the availability of incentives, aggressive infrastructure deployment, and the large number of early adopters and environmental advocates in the California vehicle market. For example, through May of 2009, California accounted for 19% of all U.S. HEV sales for that year, well above its 10.9% share of the overall market.[78] The number of HEVs per 1,000 residents in California is 1.54 compared with the national average of 0.87.[79]

Analyst Customer Demand Projections

The J.D. Power and Associates estimate of BEV sales in 2020 cited earlier is taken from a 2010 study estimating the demand for HEVs and BEVs through 2020, "taking into consideration policy initiatives, market demand drivers, and obstacles such as technological challenges, economic viability, and consumer acceptance issues."[80] The study notes that "there are major hurdles that must be overcome regarding battery-based vehicles to ensure consumer acceptance,"[81] and went on to conclude that "[g]iven the challenges that HEVs and BEVs face, and based on J.D. Power's

78 http://japan.polk.com/NR/rdonlyres/ED95423F-3682-40BC-A275-84DC1917B2FB/0/POLK_VIEW_SEPTEMBER_2009_EN.pdf
79 www.hybridcars.com/hybrid-sales-dashboard/december-2009-dashboard.html
80 J.D. Power and Associates, op. cit. p. 1
81 Ibid, p. 2.

research in automotive markets around the world, it is unlikely that global demand will reach the levels that have been widely predicted for the industry."[82]

Along similar lines, a study by Deloitte Consulting[83] identified several characteristics thought to single out those consumers "most likely to buy immediately after the early adopter wave." The consultants estimated that approximately 1.3 million people met the defined characteristics. Viewed in the context of the vehicle deployment projections described here, this is a relatively small number. For example, the Deutsche Bank projection of 676,000 electric vehicle sales in the United States in 2020 would exhaust the projected early majority customer base in less than 2 years.

Survey Results

One of the earliest attempts to survey customer demand for electric vehicles was the "hybrid household" work undertaken in 1995[84] by Thomas Turrentine and Kenneth Kurani, researchers at Institute of Transportation Studies at the University of California, Davis. The researchers defined potential hybrid households as those that "own two or more light duty vehicles and buy new vehicles of the body styles we expect will be offered as electric vehicles," and posited that "These characteristics identify households who may be able to incorporate at least one limited range vehicle into their household vehicle holdings with no, or minimal, affect on household lifestyle choices." Thus this framing of the issue specifically addressed the range limitations inherent in BEV technology. Potential hybrid households were thought to buy between 35% and 45% of all new light duty vehicles sold in California each year. In vehicle choice scenarios, nearly half of the households surveyed indicated that they would choose an electric vehicle as their next new vehicle, leading the researchers to conclude that the market potential for electric vehicles was 13% to 15% of the annual new light-duty vehicle market in California.

Many factors affecting consumer choice have changed significantly in the years since this work was conducted, such as the competing options (at the time of the survey there were no HEVs, and ICEs are now much improved) and the state of the economy. Actual placements in the early years of ZEV deployment in California were far short of the level projected by this research. Thus, the work is now dated, but the hybrid household paradigm nevertheless provides an interesting insight into potential electric vehicle customers.

There have been many more recent surveys of customer demand for HEVs, PHEVs, or other electric vehicles.[85] Two that addressed similar issues and

82 Ibid, p. 3.

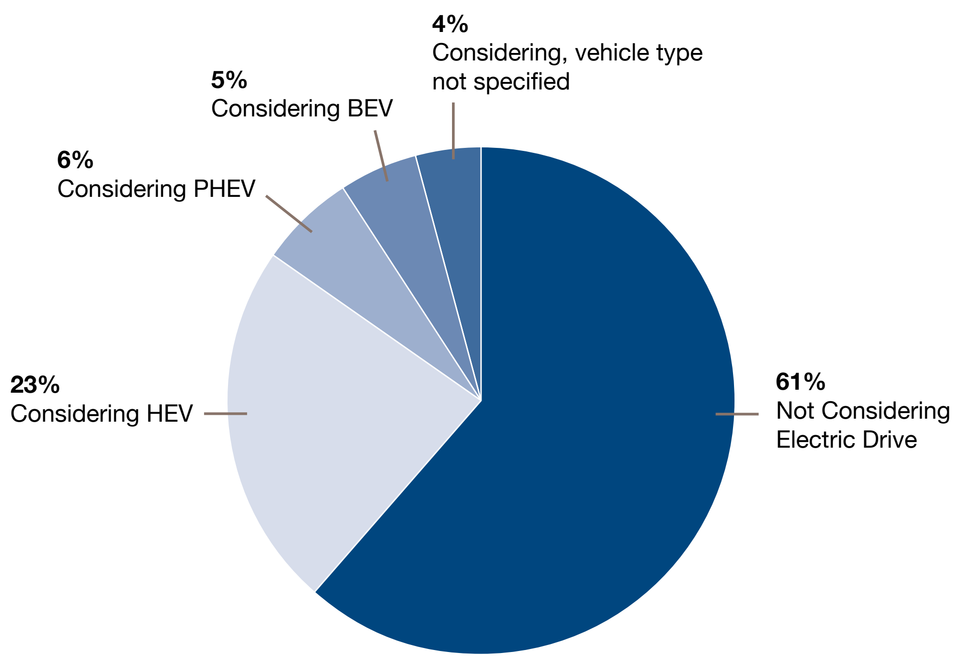
83 Deloitte Consulting LLC. *Gaining traction: A customer view of electric vehicle mass adoption in the U.S. automotive market.* New York: Author. Available at: www.deloitte.com/view/en_US/us/Industries/Automotive-Manufacturing/c3b1a4c-65c948210VgnVCM100000ba42f00aRCRD.htm

84 http://pubs.its.ucdavis.edu/publication_detail.php?id=666

85 In addition to the *Consumer Reports*[86] and Accenture[87] surveys, see, for example, Pike Research (http://blogs.cars.com/kickingtires/2010/05/carscom-survey-most-buyers-still-wary-of-electric-vehicles.html), Ernst and Young (http://green.autoblog.com/2010/06/17/ernst-and-young-survey-says-electric-vehicle-early-adopter-group-c/), and Nielsen (http://blog.nielsen.com/nielsenwire/consumer/consumers-show-high-interest-in-buying-electric-cars-but-reluctant-about-price/)

were found to be useful by ICCT were conducted by *Consumer Reports*[86] and Accenture.[87] Both found that a small but noticeable portion of the customers surveyed were considering the purchase of or were likely to buy an electric vehicle. Figures 3 and 4 show the survey results, indicating that 5% of U.S. customers are considering the purchase of a BEV as their next new car (*Consumer Reports*) and 2% state they are likely to buy a BEV in the next 2 years (Accenture US/Canada results). Given that the *Consumer Reports* survey is measuring “considering” and the Accenture survey is measuring “likely to buy,” which presumably would be a smaller proportion, these results are reasonably consistent. As a “reality check” on these projections, however, ICCT notes that although the *Consumer Reports* data show that 23% of customers are considering an HEV as their next new car, and the Accenture data show that 22% are likely to purchase an HEV in the next 2 years, the actual sales rate of HEVs in the United States is approximately 2.5%[88], a factor of nine below the percentages reported as considering or likely to buy HEVs in this survey data.

Figure 3. Consumer Preference for Next New Car, *Consumer Reports* Survey Data—United States

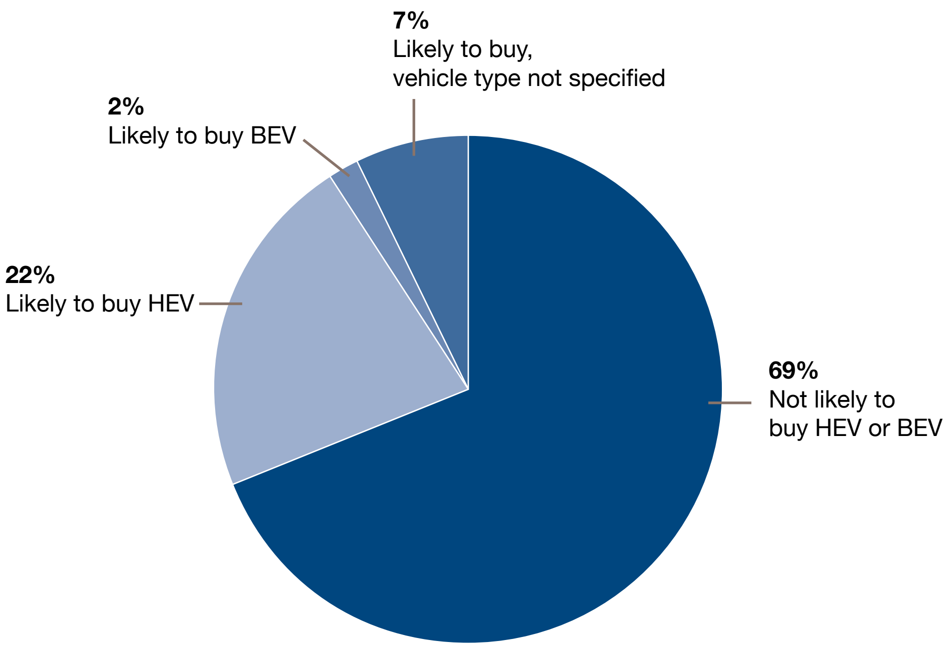


86 http://blogs.consumerreports.org/cars/2010/11/survey-interest-in-electric-cars-is-growing-but-practical-concerns-remain.html

87 http://newsroom.accenture.com/news/consumers+want+green+vehicles+to+offer+more+than+fuels+savings+accenture+finds.htm

88 www.hybridcars.com/hybrid-clean-diesel-sales-dashboard/october-2010.html

Figure 4. Consumer Preference for Car in Next 2 Years, Accenture Survey Data—United States/Canada.



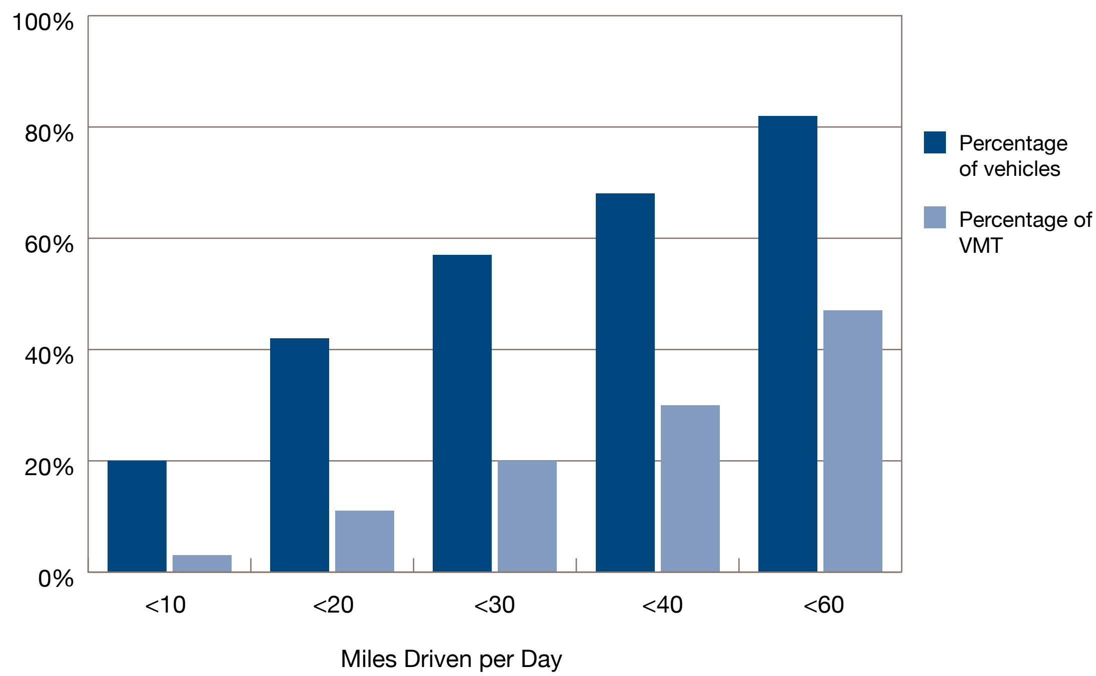
Surveys have also been conducted to gain insight into one of the key issues underlying market demand for electric vehicles—how will consumers react to the limited range and long recharge time of current BEVs? Looking first at typical driving patterns, survey data show that most day-to-day driving needs can be satisfied by current technology. The U.S. Department of Transportation reports that based on data collected for the National Household Travel Survey, the average U.S. driver drives 29 mi a day.[89] Figure 5 provides a more detailed breakdown, showing that 82% of the vehicles in the survey were driven ≤60 mi in a day, accounting for 47% of total vehicle miles traveled.[90] This same point is emphasized by Nissan in its promotional material for the Nissan Leaf, noting that 70% of the U.S. population averages ≤40 mi of driving per day and 95% average <100 mi per day.[91] (Note that the travel survey data refer to real-world driving and thus should be compared to the fuel economy label range, which for the Nissan Leaf is 73 miles.

89 www.bts.gov/programs/national_household_travel_survey/daily_travel.html

90 Vyas, A. D., Santini, D. J., & Johnson, L. R. (2009). Plug-in hybrid electric vehicles' potential for petroleum use reduction: issues involved in developing reliable estimates. Presented at the 88th Annual Meeting of the Transportation Research Board, Washington, D.C. Available at: www.transportation.anl.gov/pdfs/TA/621.PDF

91 The 100% electric, no-gas Nissan LEAF. Brochure. Nissan USA.

Figure 5. Cumulative Percentage of Vehicles and Percentage of Vehicle Miles Traveled (VMT) Accounted for by Given Trip Length (Miles) National Household Travel Survey



Even taking into account the need for a "buffer" of unused range and the occasional need to travel greater distances, this information indicates that existing technology would be more than adequate for most U.S. drivers most of the time, particularly in the two-car "hybrid households" identified by Kurani and Turrentine. Consumers, however, consistently express serious reservations about driving range:

- 94% of the respondents to the *Consumer Reports* survey stated that they "find green cars in general lacking in some way, citing a high purchase price, inadequate energy infrastructure, and limited driving range as chief concerns"[92]
- A Pike Research survey found that "fifty-four percent [of respondents] were most concerned with range anxiety in all-electric vehicles such as the Leaf, and 43 percent said they drive too far to even consider a Leaf or other EVs with a 100-mile range"[93]
- An Ernst and Young survey concluded that "significant factors making drivers most hesitant when choosing a PHEV or [B]EV as their next new vehicle are access to charging stations (69%), price (67%), and battery driving range (66%)."[94]

92 http://blogs.consumerreports.org/cars/2010/11/survey-interest-in-electric-cars-is-growing-but-practical-concerns-remain.html, op. cit.

93 http://blogs.cars.com/kickingtires/2010/05/carscom-survey-most-buyers-still-wary-of-electric-vehicles.html

94 http://green.autoblog.com/2010/06/17/ernst-and-young-survey-says-electric-vehicle-early-adopter-group-c/

This hesitation may diminish as uncertainty about real-world battery range is reduced and customers gain a better understanding of how electric vehicles can reliably meet their driving needs. Moreover, one of the primary attractions of FCEVs is that they are capable of a longer driving range and can be refueled quickly, thus avoiding range anxiety altogether. Nevertheless, such concerns will play a major role in the early electric vehicle market rollout and are part of the reason ICCT recommends a conservative approach.

Governmental Targets and Goals

Yet another perspective is provided by looking at ZEV deployment targets or goals in place in various jurisdictions around the world. Table 8 shows current targets for several countries.[95] Bear in mind that these ambitious goals assume the adoption and continuation of aggressive incentive policies and other measures.

Table 8. Selected Governmental Electric Vehicle Deployment Targets[95]

Country	Target
United States	1 million cumulative PHEVs by 2015
Germany	1 million cumulative electric vehicles (BEVs, PHEVs, FCEVs) by 2020, 5 million by 2030
United Kingdom	1.2 million cumulative electric vehicles by 2020, 3 million by 2030
France	2 million cumulative electric vehicles/PHEVs by 2020
China	5 million New Energy Vehicles (all electric drive technologies) on road by 2020, mostly BEVs 20% to 30% market share by 2030
Japan	2 million cumulative FCEVs by 2025
South Korea	50,000 cumulative units by 2020, 50% of sales by 2030s

PHEV = plug-in hybrid electric vehicle; BEV = battery electric vehicle; FCEV = fuel cell electric vehicle.

ICCT Analysis

This section provides an additional quantitative look at projected electric vehicle sales in the context of the ZEV mandate. The discussion draws on three data sources:

- California sales of HEVs as an (optimistic) indicator of potential California electric vehicle sales

95 International Energy Agency. (2009). *Technology roadmaps: Electric and plug-in hybrid electric vehicles*. Paris, France: Author; p. 18. Available at: www.iea.org/papers/2009/EV_PHEV_Roadmap.pdfv

- An estimate of the California share of the "early majority" of electric vehicle purchasers identified in the market analysis conducted by Deloitte Consulting[96]
- The *Consumer Reports* and Accenture survey data, adjusted to reflect the California rather than the national sales fraction

Data on national sales of HEVs were compiled and reported by DOE.[97] In October 2010, hybrids accounted for approximately 2.5% of the U.S. market. Data on California sales for each year are not available; however, through May of 2009, California accounted for 19% of all U.S. HEV sales for that year.[98] Based on that information, California HEV sales were estimated to be 20% of national sales throughout all reporting periods. Estimated California HEV sales for the years 2005–2009 (after 5 years on the market) were then assigned to the years 2016–2020 as a surrogate for electric vehicle sales in those years (after 5 years on the market for electric vehicles). Finally, the annual sales numbers were converted to a percentage of sales using the ARB projection of annual vehicle sales subject to the ZEV mandate.

The "early majority" customer estimate was derived from the study by Deloitte Consulting,[99] which used several characteristics thought to identify those "most likely to buy immediately after the early adopter wave":

- Higher-than-average income (>$114k)
- Urban or suburban residence
- Private garage with electrical power
- Low weekly mileage (100 mi)
- Environmental sensitivity
- Concern about dependence on foreign oil
- Political activity
- Willingness to pay for convenience

Applying those filters to the U.S. population, the Deloitte consultants estimated that approximately 1.3 million people fall into this segment, which they dubbed the "early majority." ICCT then spread those potential customers over a 10-year period to account for the fact that customers do not each purchase a new car every year, resulting in 130,000 potential customers per year for the United States. California was assumed to account for 20% of the potential early majority customers on the same basis as outlined for HEV sales.

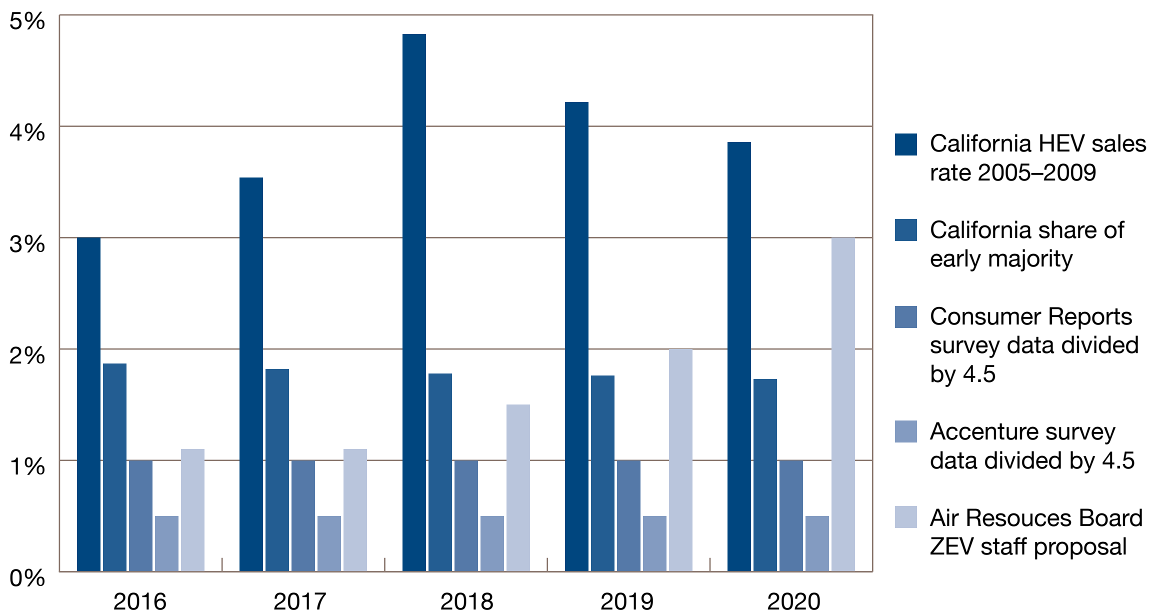
The electric vehicle market share estimates provided in the *Consumer Reports* and Accenture surveys noted earlier were multiplied by two, again to account for the

96 Deloitte, op. cit.
97 www.afdc.energy.gov/afdc/data/vehicles.html
98 http://japan.polk.com/NR/rdonlyres/ED95423F-3682-40BC-A275-84DC1917B2FB/0/POLK_VIEW_SEPTEMBER_2009_EN.pdf
99 Deloitte, op. cit.

higher percentage of advanced vehicle sales in California compared with the nation as a whole. The California survey-based market estimates were then discounted by a factor of 9, however, as an approximate correction factor in light of the nine-fold difference between HEV interest as expressed in the survey and actual HEV sales.

Figure 6 shows 2016–2020 market share estimates derived using these three methods and compares them to the existing annual ZEV requirement for Phase IV (1.1% in 2016 and 2017)[100] and the proposed annual requirements for Phase V identified by ARB staff at the November 15, 2010, public workshop (1.5% in 2018, 2% in 2019, and 3% in 2020).

Figure 6. Derived Estimates of California EV Sales vs. ARB Staff Proposal (Percentage of Sales)



These estimates clearly are imprecise, but they help bound the various projections of electric vehicle deployment in California. Viewed from this perspective, the ARB requirements are ambitious but within the range of the parameters established by this analysis. The HEV sales trend is an optimistic indicator of projected electric vehicle sales, because HEVs are more similar to conventional vehicles than electric vehicles are and therefore raise fewer questions for customers. Conversely, the “considering electric vehicle” and “likely to buy electric vehicle” segments

100 The nominal ZEV percentage requirement for Phase IV is 4%, but because of changes in the underlying credit structure between Phase IV and Phase V, the actual number of vehicles required in Phase IV using ARB standard assumptions regarding the vehicle mix is 1.1%. This figure was derived by taking the annual credit requirement in 2016 and 2017 (55,643 and 57,114, respectively) and dividing it by the average credit per vehicle in Phase IV (3.7, using 82.5% BEVs at 3 credits and 17.5% FCEVs at 7 credits). The resulting number of vehicles (15,039 for 2016 and 15,436 for 2017) was then divided by the expected vehicle sales (1,391,083 for 2016 and 1,427,853 for 2017), resulting in a sales rate of 1.1%.

are based on 2010 survey results and presumably will increase over time as customers become more familiar with the vehicles, and the 100 mi per week cutoff established for “early majority” customers by Deloitte is quite conservative.

Achieving an 80% Reduction by 2050

The governmental targets and goals outlined here are based on a variety of objectives—supporting the domestic automobile industry, gaining or capitalizing on technology leadership, increasing energy security, and maintaining progress toward climate protection goals. Many jurisdictions, including California via Executive Order S-3-05, have established a goal of reducing emissions to 80% below 1990 levels by 2050. Thus, another perspective to bring to bear on ZEV policy is to determine how quickly vehicles must be deployed for the transportation sector to achieve its share of such a reduction.

ARB staff, supported by researchers at University of California Davis, have explored this issue.[101,102] Pertinent conclusions from the ARB work are as follows:

> Given that the transportation passenger vehicle sub-sector accounts for 28% of the state’s GHG emissions today, it will be difficult to meet the 2050 goal unless a portfolio of near-zero carbon transportation solutions is pursued in the very near future. [I]t is important to accelerate the introduction of low-carbon vehicle alternatives to ensure markets enter into pre-commercial volumes (10,000s) between 2015 and 2020.
>
> Staff’s analysis shows ZEVs will need to reach 100% of new vehicle sales between 2040 and 2050, with commercial markets for ZEVs launching in the 2015 to 2020 timeframe. It takes decades for a new propulsion system to capture a large fraction of the passenger vehicle fleet for two reasons. First, new technologies require time for vehicle manufacturers to incorporate them on many or most models. For example HEVs have been sold in the US for a decade, yet they account for only 2% of new vehicle sales, and only in the past few years have a wider variety of HEV models been available. Second, once a new technology dominates the number of new models being offered for sale, it takes roughly 15 years for these vehicles to replace existing vehicles in the fleet. For example if the goal is to have most vehicles on the road in 2050 to be ZEVs, then most vehicles being sold in 2035 need to be ZEVs. Because of the first reason discussed above, this means that ZEV commercialization must begin well before 2035. Because of these considerations, it is important to accelerate the introduction of low-carbon vehicle alternatives to ensure markets emerge between 2015 and 2020.

Please note, however, that this analysis assumes that all advanced vehicle technologies are fully commercialized.[103] As discussed later, this may not turn out to be the case within the timeframe envisioned.

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101 California Air Resources Board. *White Paper: Summary of Staff’s Preliminary Assessment of the Need for Revisions to the Zero Emission Vehicle Regulation,* op. cit.

102 California Air Resources Board. Attachment B, 2050 greenhouse gas emissions analysis: Staff modeling in support of the zero emission vehicle regulation.

103 California Air Resources Board, Attachment B, op. cit., p. 5.

Other Factors Affecting Deployment

Achieving the targeted early ZEV deployments will depend, in part, on the availability of adequate refueling infrastructure. Over the long term, if ZEVs are commercialized, cost competitive over their lifecycle, and deployed in large numbers, the refueling market will evolve to meet their energy demands. In the near term, however, when vehicle numbers are small and the revenue available from vehicle refueling is limited, careful planning and policy support will be needed to ensure that infrastructure is available as needed. Even if most BEV recharging is done at home, as seems to be the case in early deployments, many logistical issues are involved in providing timely and affordable installation. For FCEVs, the availability of infrastructure will be an even more critical factor. ICCT provides a more detailed look at infrastructure issues later in the Task 4 report on complementary policies.

A tremendous amount of infrastructure deployment activity is under way worldwide. Demonstrations and targeted infrastructure rollout are taking place in Ireland, the United States, the United Kingdom, China, Israel, Japan, France, and Germany. Several related policy proceedings are also under way in California:

- The California Electric Transportation Coalition and several state agencies, in cooperation with the University of California Davis Plug-in Hybrid and Electric Vehicle Research Center and numerous stakeholders, have established the California Plug-In Electric Vehicle Collaborative Council. In December 2010, the council released a roadmap for implementation of plug-in electric vehicles in California.[104]
- The California Public Utilities Commission has opened an Alternative-Fueled Vehicle Rulemaking, which is investigating issues related to BEV and PHEV infrastructure, potential impacts on the utility grid, and the appropriates role of the electric utilities and other infrastructure providers.
- The ARB staff is developing proposals to increase the provision of hydrogen infrastructure.

Caveats

The overriding imperative is to meet customer needs. Unless the consumer sees the vehicle as equivalent or superior to a conventional or hybrid vehicle, it will be difficult to hit aggressive deployment rates, particularly at a price premium. Subsidies will help offset increased costs but will not fully account for the increased cost to the consumer in the near term.[105] Meanwhile, many factors other than purchase cost—perceived reliability, dependability, maintenance costs, resale value, utility, luxury, ride, performance, safety, and, perhaps most important, the image the vehicle projects—affect the purchase decision. Although early adopters are less risk averse, they are only a small portion of the market, and mainstream customers are very risk

104 California Plug-In Electric Vehicle Collaborative. *Taking Charge: Establishing California Leadership in the Plug-in Electric Vehicle Marketplace*. Available at www.evcollaborative.org/evcpev123/wp-content/uploads/2010/07/Taking_Charge_final2.pdf

105 See, for example, Electrification Coalition, op. cit., p. 131.

averse in the face of uncertainties. It is instructive that after 10 years on the market, sales of HEVs—which are superior to conventional vehicles from a performance standpoint—still only accounted for about 2.5% of annual U.S. sales.

Implications for Policy

Given the seriousness of the climate problem, and the need for rapid electric vehicle deployment to reduce transportation emissions, it can be argued that the ARB ZEV sales mandate for the 2020 timeframe should be set at a level that “locks in” a substantial portion of the deployment already being projected by manufacturers. The NRDC analysis makes this point, stating

> the ZEV program can be justifiably strengthened above current requirements over the MY2015 to MY2020 time period. Doing so will allow the ZEV program to better reflect real changes in the industries’ expected product offerings and help ensure automakers are investing to commercialize technology necessary to reach post 2020 GHG emission reduction goals. [106]

Although this view may at first glance seem self-evident, it assumes that technology will progress and costs decline per the manufacturer and analyst projections and that customers will readily accept the vehicles. Given that in the past ARB has had to repeatedly amend the ZEV program to align with slower-than-anticipated progress, it also is important to consider what happens in a world where improvements do not materialize as rapidly as expected. In that scenario, the per-vehicle cost remains high, and a large ZEV requirement places a significant burden on manufacturers and diverts scarce resources from research and development to deployment. Uncertainty regarding the size of the future market comes on several fronts—cost, vehicle functionality, and consumer acceptance.

Meanwhile, in a world where aggressive electric vehicle deployment plans in California and in other jurisdictions succeed, the California market will account for only a relatively small portion of expected global sales. For example, using the most optimistic numbers from Figure 2 for global electric vehicle sales in 2020 (4 million per Deutsche Bank), a California ZEV requirement of 3% (45,000 vehicles) amounts to approximately 1% of global electric vehicle sales. Even if that number is tripled to take into account additional sales in Section 177 states that have adopted the California passenger vehicle program, it is unlikely under that scenario that any feasible ZEV requirement would have a noticeable upward effect on production.

Finally, it is important to consider the need for consistency, stability, and a long-term policy signal to manufacturers. If the stringency of the requirement is in question, as has been the case with the ZEV program in the past, it diminishes the strength of the incentive provided to manufacturers. Thus, there is value in establishing a target that is not viewed as subject to future revision and backtracking.

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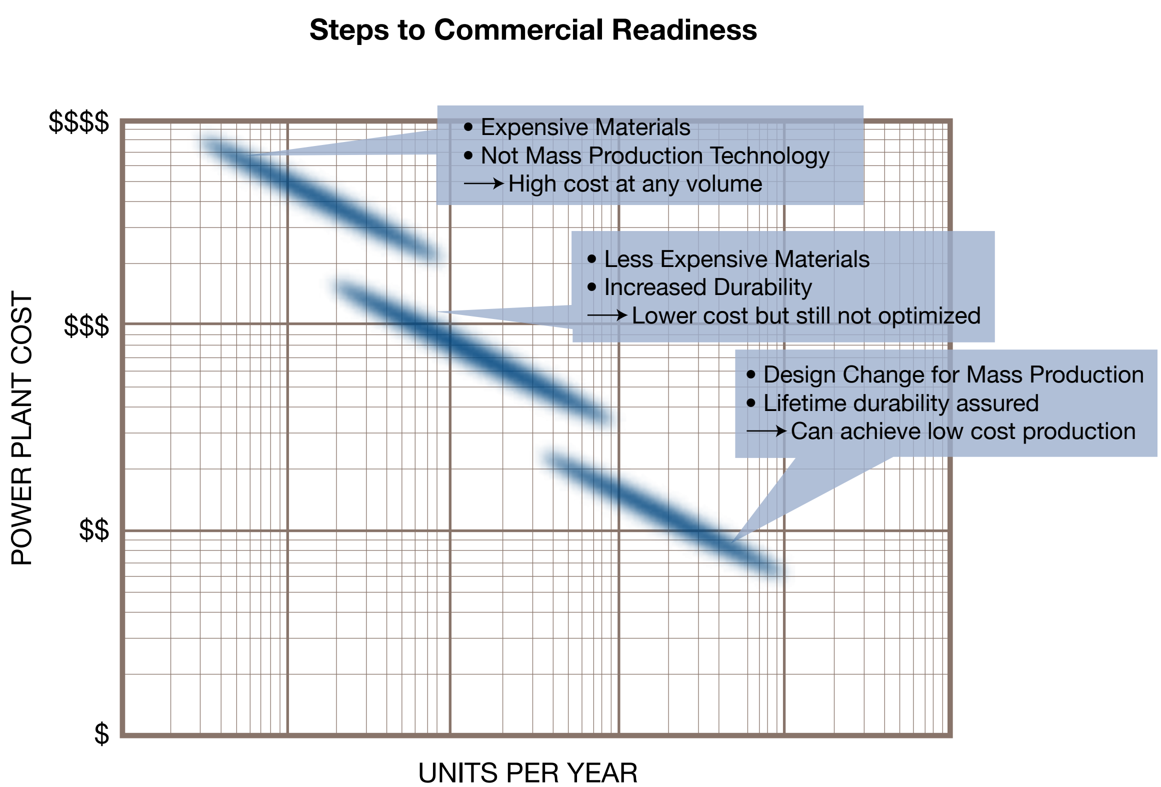
106 Mui & Baum, op. cit. p. 6.

Until technology matures, there will always be a need for additional research and development expenditures through several iterative generations of technology, with each successive generation reducing cost. But increased production volume also reduces per-unit cost. Figure 7 illustrates in conceptual form how cost is reduced by both technical progress and increased production volume. Note that the cost versus volume curve is not continuous at the precommercial stage—rather it goes through a series of "steps" as material and process advancements pave the way for commercial readiness.

Figure 7. Fuel Cell Electric Vehicle (FCEV) Power Plant—Cost vs. Volume



Finding an appropriate policy balance between technical improvement and deployment is a significant challenge. This brings to light one of the tradeoffs involved in ZEV policy—what is the appropriate emphasis to be placed over time on research and development as opposed to large scale deployment? Figure 8 summarizes in simplified form the relationship between the state of future technical and marketing progress and the impact of the ZEV requirement.

Figure 8. Impact of Zero Emissions Vehicle (ZEV) Mandate at Different Levels of Future Technical Progress

		Future Technical Progress	
		As Expected	**Falls Short**
ZEV Requirement	**Low**	Mandate not controlling Commercialization proceeds faster than ZEV requirements	Mandate sets floor Low deployment numbers Lower investment in deployment
	High	Mandate not controlling Commercialization proceeds on pace with or faster than ZEV requirements	Mandate sets floor High deployment numbers Higher investment in deployment

Any consideration of the role that the ZEV mandate can and should play in encouraging vehicle electrification also needs to take into account the degree of commitment to the technology being evidenced by vehicle manufacturers. The "value added" of the ZEV mandate in accelerating technology development is at its greatest when manufacturers are not aggressively pursuing electrification for their own competitive reasons. This was certainly the case when the mandate was first conceived in 1990 and arguably has been the case throughout most of the mandate's history. As noted earlier, however, manufacturers today are investing heavily in BEVs and FCEVs and in some cases are making electrification the centerpiece of their future strategy. The number of vehicles expected to be produced globally by 2020 will be substantial if their efforts succeed.

Viewed in this context, the unique contribution of the ZEV mandate is its ability to sustain research and development during periods of uncertainty and market challenge. Manufacturers will be facing such a period later in this decade as they seek to move from early adopters to a broader range of customers. Thus, in ICCT's view the mandate can serve as a critical "floor" that will ensure continued development in the face of technical or market challenges.

ENVIRONMENTAL IMPACTS

Unlike vehicles that rely on combustion engines for motive power, ZEVs have the potential to be truly zero emission, but their real-world performance depends on the specific technology pathways used to provide their fuel. Thus, it is important to address the GHG and criteria pollutant emissions and other environmental impacts that result from the production and distribution of the fuel compared with similar effects from conventional fuels. This section provides a brief overview of estimated air, water, and waste impacts from ZEVs, including upstream impacts from refueling. Additional attention is given to upstream air pollution and GHG impacts in the Task 2 report on metrics to measure ZEV compliance and performance.

Air Pollution

The California ARB staff recently released an analysis of potential power plant emissions under scenarios that achieve the 33% renewable electricity target.[107] This analysis provides information on projected criteria pollutant emission rates in 2020. Using information from that analysis, ICCT calculated the criteria pollutant emission rates in grams per mile that would result from generating the electricity needed to power BEVs. This calculation assumes 0.3 kWh/mi electricity consumption for BEVs and takes into account battery/charger losses. The calculated emission rates are shown in Table 9. In-state and out-of-state incremental NO_x emissions for electricity generation are significantly less than ICCT-estimated upstream refinery emissions, whereas organics are comparable and fine particulates may be slightly higher. Taking into account tailpipe and petroleum distribution emissions, vehicle electrification should have a very positive overall effect on ozone and fine particulates.[108]

Table 9. Electric Vehicle Electricity Criteria Pollutant Emission Rates in Grams per Mile, 2020, 33% Renewable Electricity Standard (RES) Scenarios

	33% RES—High load		33% RES—Low load		33% RES—Incremental	
	CA	WECC*	CA	WECC	CA	WECC
ROG	0.0030	0.0032	0.0029	0.0030	0.0035	0.0043
NO_x	0.0151	0.0906	0.0157	0.1108	0.0118	0.0141
SO_x	0.0028	0.0279	0.0031	0.0345	0.0012	0.0014
$PM_{2.5}$	0.0044	0.0121	0.0043	0.0142	0.0051	0.0053

**California plus other Western Electricity Coordinating Council (WECC) states.*

ROG = reactive organic gases; NO_x = nitrogen oxides; SO_x = sulfur oxides; $PM_{2.5}$ = fine particulate matter (<2.5 μ).

Another perspective is provided by Table 10, which shows TIAX 2007 estimates of well-to-wheel NO_x emissions from light-duty conventional, BEVs and FCEVs.[109] These numbers represent emissions occurring in 2017 from new

107 California Air Resources Board. (2010). *Proposed regulation for a California renewable electricity standard, staff report: Initial statement of reasons*. Appendix D: Supporting Documentation for the Environmental Analysis, pp. D-25–D-28. Available at: www.arb.ca.gov/regact/2010/res2010/res10isor.pdf

108 We note that power plants and refineries are covered by the South Coast RECLAIM program for NO_x and that new and significantly expanded refineries and power plants are required to provide offsets under the New Source Review program.

109 TIAX. (2007). *Full fuel cycle assessment, well to wheels energy inputs, emissions, and water impacts*. CEC-600-2007-002-D. pp. 3–5. Available at: www.energy.ca.gov/2007publications/CEC-600-2007-002/CEC-600-2007-002-D.PDF.

vehicles starting with model year 2010. Total light-duty vehicle NO_x emissions for vehicles burning reformulated gasoline were estimated at 0.29 grams per mile (g/mi) on a well-to-wheel basis, with 0.04 g/mi urban emissions. Electric vehicles are estimated to result in 0.01 g/mi for electricity from natural gas (including natural gas production and transportation) mixed with state-mandated levels of renewable electricity over that same timeframe, with 0.001 g/mi urban emissions. Urban emissions are defined as fuel cycle emissions that occur in California, assuming that increased power plant emissions are fully offset.

Table 10. TIAX Estimated Well-to-Wheels Nitrogen Oxide (NO_x) Emissions, 2017, Model Year 2010 and Newer Vehicles

	NO_x Emissions, g/mi	
	Total	**Urban**
Light duty auto	.29	.04
Battery electric vehicle	.01	.001
Fuel cell electric vehicle	80–90% < RFG	80–90% < RFG

RFG = reformulated gasoline.

TIAX also estimated significant reductions in other ozone precursors and fine particulates for both BEVs and FCEVs. Per the TIAX report volatile organic compound emissions would be reduced by 90% or more. Hydrogen production NO_x mass emission rates are estimated to be 80% to 95% less than for reformulated gasoline for both total and urban emissions over that same timeframe. Volatile organic compound emission reductions for this pathway were estimated at approximately 40% for total emissions and >90% for urban emissions.

Fine particulate emission rates are also estimated to be smaller for electric and FCEVs, except when coal is used as a fuel source (including coal production and transport). As noted in the TIAX report, some of the total emissions may not occur in California. Some stationary source emissions counted in the total may be offset through New Source Review (in particular new power plants) or RECLAIM. Table 11 shows the emission components included in the TIAX estimates.

Table 11. Emissions Included in TIAX Estimates

Emissions	Urban	Total
Petroleum—NO_x, VOC, fine particulates	Marine vessel emissions within 100 mi of California In-state rail, local truck, pipeline delivery Storage/fueling losses Vehicle tailpipe	Crude production and transportation Refining Total global marine transport Rail, local truck delivery Storage/fueling losses Vehicle tailpipe
Electricity—Natural gas and RPS–NO_x, VOC, fine particulates	In-state production and transportation of natural gas	Global production and transportation of natural gas Natural gas power plant stack emissions
H_2 FCEV—SMR–NO_x, VOC, fine particulates	In-state natural gas production H_2 compression energy usage H_2 transportation	Global natural gas production H_2 compression energy usage H_2 transportation H_2 plant emissions

NO_x = nitrogen oxides; VOC = volatile organic compounds; H_2 FCEV = hydrogen fuel cell electric vehicle; SMR = steam methane reforming.

Other states, including states that export electricity to California, have different utility mixes that in some cases rely much more heavily on coal and raise the question of environmental impacts in these other areas. To provide a national context, Table 12 shows results from a national EPRI/NRDC study of the emission impact of PHEVs.[110] The study found that most people would experience air quality improvements in ozone and fine particulate levels in the year 2030, whereas a much smaller number (primarily those living near large power plants) would receive disbenefits.

Table 12. National Emission Impacts of PHEV Deployment

Pollutant and threshold	Percent of Population	
	Benefits	Disbenefits
Ozone 8-hr (0.25 ppb change)	61%	1%
$PM_{2.5}$ daily (0.1 µg/m3)	82%	3%
$PM_{2.5}$ annual (0.1 µg/m3)	38%	1%

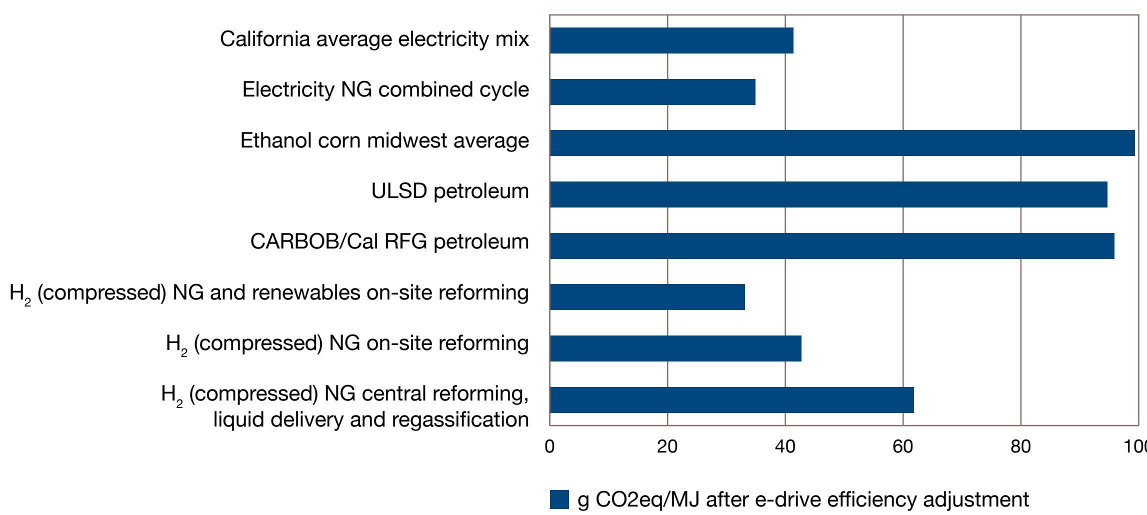
ppb = parts per billion; $PM_{2.5}$ = fine particulate matter (<2.5 µ).

110 EPRI/NRDC. (2007). *Environmental Assessment of Plug-in Hybrid Electric Vehicles*. Volume 2 Table 6-6.

GHG Emissions

This section provides some existing estimates of GHG emissions. A more detailed discussion of how to account for ZEV GHG emissions under fleetwide GHG standards is provided in the Task 2 report on metrics. GHG emissions can be estimated based on either marginal or average electricity usage. Some resources such as nuclear will be used as "base load" regardless of whether electric vehicles are supplying additional demand, whereas natural gas "peaking" plants are more likely to operate on the margin. Figure 9 shows a comparison of the GHG benefits of BEVs and FCEVs based on the methodology used in California ARB's 2009 Low Carbon Fuel Standard (LCFS). The LCFS compares the GHG emissions per MJ on a well to tank basis, then makes an adjustment for the higher tank to wheels efficiency of electric and FCEVs. As Figure 9 indicates, electric drive vehicles provide a significant well-to-wheels GHG reduction as compared to conventional petroleum fueled vehicles.

Figure 9. Estimated Well-to-Wheels GHG Intensity vs. Petroleum



NG = natural gas; ULSD = ultra-low sulfur diesel; CAROB = California reformulated gasoline blendstock for oxygenate blending; RFG = reformulated gasoline.

The California ARB's recent analysis of potential electric grid emissions under 33% renewable electricity scenarios[111] also provides information on projected GHG pollutant emission rates in 2020. These projections assume that the current trends in fuel economy standards through 2016 are continued out to 2020. Similar to the calculation in Table 9, ICCT calculated GHG emission rates in grams per mile that would result from generating the electricity needed to power BEVs.

111 California Air Resources Board, *Proposed regulation for a California renewable electricity standard, staff report: Initial statement of reasons,* op. cit.

Table 13 shows a comparison of CO_2 emissions from 2020 internal combustion engines (assuming that continuing improvements would be made at the same rate of progress as under California's Pavley I GHG standards) to upstream emissions from BEVs under California's 33% renewable electricity standard. Electric vehicles will continue to have a significant advantage, whether calculated based on average or marginal electricity generation.

Battery manufacturing will create some upstream GHG emissions that are addressed in papers by Argonne National Laboratory and the Swiss Federal Laboratories for Materials Science and Technology.[112] Based on these data, the battery manufacturing GHG impacts for a small 200 km (120 mi) BEV are likely to be approximately 5% of the GHG impacts of a comparable internal combustion engine vehicle.

Table 13. Electric Vehicle (EV) Electricity CO_2 Emission Rates in Grams per Mile, 2020, 33% Renewable Electricity Standard Scenarios

2020 Internal Combustion Engine		EV @ 0.25 kWh/mi		EV @0.28 kWh/mi	
Tailpipe	Tailpipe+ Upstream	Incremental	Average	Incremental	Average
219	274	112	66–74	125	73–82

Water Pollution

Petroleum production, refining, and distribution create the risk of environmental contamination. Oil spills in California were estimated at >800,000 gal in-state for 2006. In addition, refineries are estimated to generate 20 to 40 gal of wastewater for every barrel of petroleum refined.[113] Refinery wastewater impacts can occur from routine discharges in a treatment system that does not address a specific pollutant, residual levels that remain after treatment, or accidents or incidents. Examples of releases include copper, selenium, and chlorine.[114]

In-state power plants typically have discharges from cooling water systems that can include concentrated levels of the dissolved solids contained in intake water, as well as minor process wastes. Modern plants can be designed to virtually eliminate

112 Battery manufacturing GHG impacts of a 200-km (124 mi) Golf LiMn2O4 would be approximately 5% of conventional vehicle life-cycle emissions, according to Notter, D. A., Gauch, M., Widmer, R., Wager, P., Stamp, A., Zah, R., et al. (2010). Contribution of Li Ion Batteries to the Environmental Impact of Electric Vehicles. *Environmental Science and Technology*, 44, 6550–6556. Available at http://pubs.acs.org/doi/suppl/10.1021/es903729a. GHG manufacturing emissions are 8 g/mi higher for a PHEV 64-km (40-mi) range compared with a non–PHEVs, based on data from Gaines, L., Burnham, A., Rousseau, A., and Santini, (2008). Sorting through the many total-energy-cycle pathways possible with early plug-in hybrids. *World Electric Vehicle Journal, 2*, 74–96.

113 Ellis, M., Dillich, S., Margolis, N. (2003). Industrial Water Use and Its Energy Implications, Table 3. Available at: www1.eere.energy.gov/industry/steel/pdfs/water_use_rpt.pdf. Effluent Guidelines Program Plan www.epa.gov/waterscience/guide/304m/2004/tsd-section7.pdf.

114 www.sfgate.com/cgi-bin/article.cgi?f=/c/a/2009/12/22/BAK21B7NKM.DTL

wastewater discharges.[115] At some older natural gas–fired boilers, cooling water is withdrawn (typically from a bay or the ocean) and then returned to the same source at a higher temperature. This thermal impact can have a negative effect on water quality and will be addressed by a recent California State Water Resources Control Board decision to phase out once-through cooling.[116] Hydrogen production from steam methane reforming is not expected to generate water pollution.

Water Consumption

The petroleum refining industry consumes >1 gal of water for every gallon of crude petroleum it refines.[117] Water usage for biofuels production is much higher. The electricity used to power an electric vehicle, based on a modern combined cycle natural gas power plant with evaporative cooling (on the order of 0.21–0.33 gal/kWh or approximately 0.06–0.09 gal/mi) will likely require a comparable amount of water on a per-mile basis. Fossil power plants with dry cooling systems and renewable resources such as wind and photovoltaic solar use much less.[118]

Some existing fossil plants use "open loop" cooling that uses seawater and then returns it to the original source with much lower consumption; as noted earlier, however, this process is being phased out. Note that this comparison does not include water consumed during oil production such as steam injection in Kern County heavy crude oil fields or water consumption for fossil fuel production. Nuclear fuel processing is reportedly a heavy water consumer,[119] although nuclear is considered constrained from increasing production further to supply electric vehicles. [120]

Hydrogen production from steam methane reforming is not expected to consume significant quantities of water. Hydrogen production from complete hydrolysis of water would consume slightly >1 gal of water per pound of hydrogen, not including upstream energy supplies. Water consumption on a per-mile basis, including upstream energy supplies, could be more or less than petroleum, depending on the energy source for the hydrolysis and the amount of water used to produce crude oil.

Waste

Refineries generate petroleum coke and other waste materials such as spent catalyst. Natural gas and renewable resources such as wind and solar will generate

115 Final Commission Decision Victorville II Hybrid Power Plant, California Energy Commission, p. 228. www.energy.ca.gov/2008publications/CEC-800-2008-003/CEC-800-2008-003-CMF.PDF

116 CWA SECTION 316(B) REGULATION Power Plant Once-Through Cooling Regulation. Available at: www.swrcb.ca.gov/water_issues/programs/npdes/cwa316.shtml

117 www.epa.gov/waterscience/guide/304m/2004/tsd-section7.pdf

118 California Energy Commission. Pier Program Summary Wet, Dry, Hybrid Wet/Dry, and Alternative Cooling Technologies. Available at: www.energy.ca.gov/research/environmental/project_fact_sheets/100-98-001-6.html; Sutter Power Project Fact Sheet, Available at: www.energy.ca.gov/sitingcases/sutterpower/factsheet.html

119 King, C. W, & Webber, M. E. (2008). The Water Intensity of the Plugged-In Automotive *Economy, Environmental Science and Technology, 42,* 4305–4311.

120 California Air Resources Board. Rulemaking to Consider the Adoption of a Proposed Rulemaking for a California Renewable Electricity Standard: Initial Statement of Reasons (ISOR) Appendix D, June 2010; Elgowainy, A., Burnham, A., Wang, M., Molburg, J., & Rousseau, A. (2010). *Well-to-wheels analysis of energy use and greenhouse gas emissions of plug-in hybrid electric vehicles*. ANL/ESD/10-1. Argonne, IL: Argonne National Laboratory, p. 86.

electricity and hydrogen without significant waste issues from operation. Nuclear and coal (primarily out of state) electric plants serving California's baseload generate waste although nuclear capacity is considered constrained.

Lithium batteries have the potential for reuse as stationary power storage after they have exceeded their automotive service lifespan, although the economics of using spent automotive batteries versus other less expensive batteries not built to automotive specifications are not proven. Another option is recycling facilities such as the Lancaster, Ohio, facility funded by the stimulus program.[121] In the European Union, an 85% reuse and recycling requirement for end-of-life vehicles will encourage battery reuse and recycling.[122] Fuel cells are expected to be recycled to recover platinum.

FINDINGS

In light of the foregoing discussion, ICCT offers the following summary observations:

1. ZEV technology is advancing rapidly, with major manufacturer investment in vehicle technology development and deployment. Analyst estimates, manufacturer plans, and governmental targets all point toward significant future deployment. These trends surpass any seen before.

2. Nevertheless, there is substantial uncertainly regarding commercialization potential. Many studies point toward continued long-term cost penalties for advanced technology vehicles. However, some manufacturers are proceeding with aggressive production plans. Thus, there appears to be a disconnect between the costs projected by most analysts and the behavior of some manufacturers.

3. As shown in Figures 2 and 6, analyst projections of future production volume for the most part are consistent with the targets set forth by ARB staff at the November 15, 2010, workshop, but caution is advisable. As Dr. Anderman noted in his comments on the ARB white paper, "Technological breakthroughs with a positive impact on [battery] performance are always possible but cannot be predicted, nor can policies be based upon them."[123] In addition, such projections rarely assess consumer behavior and risk aversion, which are critical determinants of customer demand. One of the hard lessons learned in the course of the ZEV program is that a mandate by itself cannot guarantee progress, let alone commercialization.

4. Vehicle deployment targets need to be defined from the bottom up (the number that can feasibly be produced and sold in a given timeframe) as well as from the top down (the number needed to meet 2050 GHG reduction targets). Given

121 US Department of Energy. Recovery Act awards for electric drive vehicle battery and component manufacturing initiative. Available at: www1.eere.energy.gov/recovery/pdfs/battery_awardee_list.pdf

122 Directive 2000/53/EC of the European Parliament and of the Council of 18 September 2000 on end-of life vehicles, article 7.

123 Anderman, op. cit., p. 3.

the long timeframe needed to accomplish a transition to electric drive, the key objective for the near term is to ensure that the program provides steady, sustainable progress.

5. Over the long run, the ZEV program will transition into the LEV IV GHG fleet average. Thus, the mechanism for achieving the 2050 GHG target in reality will be a stringent fleet average, not initial ZEV production volume. More stringent fleet average standards will encourage and ultimately likely require vehicle electrification.[124]

6. In the long term, a properly constructed ZEV program can be viewed as a transitional effort to support investment in a broad range of technologies. This view will maximize the availability of low carbon vehicles to meet the increasingly stringent future fleet average while leaving the way open for other technical advances that can achieve significant emission reductions.

7. More generally, the ZEV mandate can now be viewed as a "floor," establishing minimum production requirements that will maintain some level of investment and momentum even if manufacturer deployments and the voluntary programs in other jurisdictions do not move forward as planned.

8. ZEV technology provides environmental benefits now, but further efforts will be needed to ensure that in the future the vehicles achieve their full emission reduction potential. Policies such as the Renewable Electricity Standard, renewable hydrogen policies, California ARB's Low Carbon Fuel Standard, and emerging climate policies including cap-and-trade programs covering the transportation and fuel sectors will play important roles in maximizing the environmental benefits of these technologies.

124 Lache et al., *Electric Vehicles,* op. cit., p. 18.

RECOMMENDATIONS

As history has shown, it is difficult to predict cost and vehicle deployment trajectories for advanced technology vehicles. Therefore, the relevant question is as follows: How should ZEV policy proceed in the face of this uncertainty? More specifically, what does this assessment suggest regarding the appropriate deployment targets for 2018 and beyond? ICCT makes the following recommendations based on its assessment of technology status and cost projections:

1. ICCT recommends continuation of the ZEV program in recognition of its critical role in encouraging continued long-term technology development. At a minimum, it will ensure ongoing investment in vehicle electrification in the event of slower than expected technical progress.

2. ARB staff is considering defining a firm 2026 transition date at which point the ZEV requirements would be removed and replaced by reliance on a fleet average GHG standard. This approach will provide the stable long-term signal that is important to manufacturers. ICCT supports this overall direction while recognizing that such a transition requires the imposition of a sufficiently stringent fleet average standard, and work is needed to firmly establish the appropriate date.

3. ARB staff should begin now to define how upstream GHG emissions from electric drive vehicles can be accurately accounted for in the fleet average emission calculations. Generic emission factors are adequate when there are small numbers of vehicles, but a more precise accounting will be needed when electric drive vehicles enter the fleet in large numbers. Such an accounting should be scalable to the national level to ensure compatibility with the federal program. A more complete discussion of this topic is provided in the Task 2 report on metrics.

4. The ARB staff proposal would retain without significant change the existing requirements through 2017. ICCT supports this approach, which is consistent with viewing the ZEV program as a “floor” as noted earlier.

5. With regard to future deployment targets, for Phase V (2018–2021) ARB staff has proposed a target increasing from 1.5% to 4% of sales, and for Phase VI (2022–2025) a target increasing from 5% to 8% of sales. More aggressive targets would help lock in the deployment numbers anticipated by manufacturers and ensure significant investment in vehicle deployment. In light of the considerable uncertainty surrounding future progress and customer demand, however, it is important to recognize that if sales do not take off as planned, high targets will divert funds from investment in research and development to manufacturing expense to support deployment.

   On balance, ICCT recommends caution and recommends targets consistent with (although slightly lower than) the ARB proposal when expressed in terms of the number of vehicles required. As discussed in the Task 2 report ICCT recommends a credit structure that differs somewhat from the ARB staff proposal, such that the percentage requirements set forth by ARB and ICCT are not strictly comparable. Using ICCT's framework, the percentage requirement would increase from 1.5% to 4% in Phase V and from 7% to 10% in Phase VI. A more complete comparison of the ARB and ICCT credit structures and the impact on the required number of vehicles is provided in the Task 2 report.

6. ARB staff has asked for comment on whether there should be an Enhanced AT PZEV (PHEV) requirement in the ZEV regulation. In keeping with the overall theme of providing flexibility, ICCT believes that the regulation should recognize and appropriately credit Enhanced AT PZEVs, but there should not be a specific requirement that such vehicles be produced.

7. ICCT agrees with ARB staff that the net cost evaluation should take into account sales outside of California. If other jurisdictions follow through on announced plans and customers actually purchase the vehicles at the proposed levels, California deployment will be only a portion of global deployment over the next several years. This should be kept in mind for cost estimation purposes.

8. ARB staff should explicitly consider LEV III GHG and ZEV interactions with the Low Carbon Fuel Standard, the Renewable Electricity Standard, and emerging federal and state climate policy and as appropriate consider regulatory modifications to programs to maximize synergies.

THE INTERNATIONAL COUNCIL ON CLEAN TRANSPORTATION

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