Technical Assessment of CO_2 Emission Reductions for Passenger Vehicles in the Post-2025 Timeframe

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About the authors:

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About the report:

With over 60 years of collective experience and deploying state-of-the-art OMEGA modeling, the authors have carried out extensive technical analysis summarized in this report examining what CO_2 reductions may be possible considering technologies, vehicle cost and overall cost savings to customers when fuel savings are considered, to help initiate and facilitate future analysis and discussion. The report does not recommend adoption of specific CO_2 emission standards for 2026 and beyond. Additional technical and economic analyses, and input from all interested stakeholders, are necessary prior to adoption of new emissions performance standards. This report was prepared with support from Environmental Defense Fund, a non-profit, non-governmental, non-partisan environmental advocacy group with over two million members. Guided by science and economics, Environmental Defense Fund is committed to practical and lasting solutions to the most serious environmental problems. For more information, please visit www.edf.org

Executive Summary

The purpose of this paper is to analyze the feasibility and cost-effectiveness of reducing carbon dioxide ("CO_2") emissions from passenger vehicles to below the current 2025 model year standards. The focus is nationwide, although the results are also relevant for California and its CO_2 reduction efforts. The timeframe we have chosen to evaluate is the 2030 model year.

Because our analysis is sharply focused on technical and cost considerations, we do not make specific policy recommendations, though it is important to consider the need for lead time and market adjustment necessary to implement the technologies that would provide further CO_2 emission reductions. For this purpose we have assumed the current 2025 model year CO_2 standards are unchanged and become our baseline, and that efforts to further reduce CO_2 emissions would become effective with the 2026 models.

The reasons we are exploring further reductions in CO_2 emissions are twofold. First, the indisputable scientific findings that the climate is warming and humans are contributing factors, and the resulting risks to our planet and way of life, indicate that additional reductions of CO_2 are necessary. To achieve an 80 percent reduction in CO_2 emissions economy-wide by 2050, an often suggested goal[1], very large reductions of CO_2 emissions from passenger vehicles will be needed, and this will require a transition to zero or near-zero emission vehicles (ZEV).[2] We have kept these climate goals in mind as we evaluate the CO_2 reductions possible in 2030, and in particular consider whether the reductions possible by 2030 put us on a path consistent with the reductions and technologies needed to meet longer term climate goals for 2050.

Second, during 2016 and 2017, EPA and California Air Resources Board (CARB) have been undertaking a mid-term evaluation (MTE) of the current 2022-2025 model year CO_2 standards, and CARB is also reviewing its ZEV requirements for the same years.[3] The extensive and updated information supporting the MTE provides an opportunity to consider the latest information on technologies to reduce CO_2 emissions, and evaluate whether greater emission reductions beyond the 2025 model year are feasible.

We began by reviewing the EPA, NHTSA and CARB Technical Assessment Report (TAR, July 2016), EPA's updated Proposed Determination and supporting documents (PD, Nov. 2016), the Final Determination (FD) and other documents to determine if conventional technologies[4] are available to achieve reductions beyond those the current 2025 CO_2 standards are projected to

[1] For example, 165 subnational governments have signed the Under2MOU to collaborate on limiting global temperature increase to less than 2 degrees Celsius. The MOU identifies that achieving this goal means pursuing GHG emission reductions consistent with a trajectory of 80 to 95 percent below 1990 levels by 2050. *See* Subnational Global Climate Leadership Memorandum of Understanding, http://under2mou.org/ (last visited February 23, 2017).
[2] It is possible that other vehicle technologies, very low carbon fuels and new mobility services may also contribute to reducing CO_2 in the future.
[3] In January 2017, EPA completed its MTE, concluding that changes to the current 2022 to 2025 CO_2 emission standards are not necessary. CARB's hearing on its review is scheduled for March, 2017.
[4] We define "conventional technologies" as technologies used on some vehicles today, or projected to be used by 2025, including non-plug-in hybrids. Conventional technologies do not include ZEVs which are defined as battery electric vehicles, plug-in hybrid electric vehicles, and fuel cell electric vehicles.

deliver. We found there are underutilized conventional technologies available to further reduce CO_2 emissions, but the reductions are relatively limited for many manufacturers (e.g. 10 to 30 gram per mile (gpm) reduction).[5] Some additional CO_2 reduction is likely to be achievable if several emerging conventional technologies become commercially available. However ZEVs, which provide much greater CO_2 reduction per vehicle than vehicles using only conventional technologies, will be needed to achieve larger reductions in CO_2 emissions, as demonstrated below.

We reviewed many recent announcements by vehicle manufacturers of new ZEV models (battery electric (BEV), plug hybrid (PHEV) and fuel cell) planned for introduction. We believe this is an important indicator of whether the market for these vehicles will grow. We found that the current number of affordable, mass market ZEV models will likely triple by 2020, compared to mid-2016. In addition, the electric range of some of these vehicles has significantly increased; for example the Chevy Bolt BEV has a range of 238 miles and the Chevy Volt PHEV has a range of 52 miles. Increasing vehicle model selection and longer range are two developments that should help the market for ZEVs grow.

We also note that several vehicle manufacturers have publicly stated that ZEVs will account for 15 to 25 percent of worldwide sales by 2025. With the fraction of total sales that are ZEV currently in the low single digits, these public statements by OEMs suggest they expect ZEV vehicles to become a main stream product in the near future.

Another important trend supporting growth in the market for ZEVs is the rapidly declining cost of lithium ion batteries. We reviewed the available literature on future battery pack costs, including a study provided by the International Council on Clean Transportation (ICCT) which projects battery costs to 2030 and concludes that a 100 mile BEV could cost less to manufacture than a conventional vehicle. The study likewise concludes that longer range BEVs and PHEVs would remain a few thousand dollars more costly than a conventional vehicle. Our analysis uses these lower manufacturing costs, which we concluded are appropriate for 2030 when higher volume sales of ZEVs are likely. The ICCT cost estimates for ZEVs in 2030 are significantly lower than the costs projected and used by EPA in their TAR and recent PD and FD (see Table 4 in Section V).

To quantify the CO_2 emission reductions feasible by 2030, and the cost of achieving these reductions, we employed the updated OMEGA model relied upon by EPA in preparing its analysis for the PD and FD. Based on a large number of technical and cost studies, EPA determined effectiveness and cost estimates for 80 technologies, and combined them into thousands of technology packages. Using technology packages helps prevent the model from selecting multiple technologies that are seeking to reduce the same engine or vehicle inefficiency. The OMEGA model then determines for each vehicle manufacturer's models the least costly technology packages needed to achieve a predetermined CO_2 emission reduction target.

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[5] See Figure 4. Slightly greater CO_2 reductions may be achievable if several emerging conventional technologies are commercialized. These are discussed in the TAR and PD documents, but are not included in EPA's OMEGA model that was used to provide a quantitative assessment of the feasibility of the 2025 CO_2 standards.

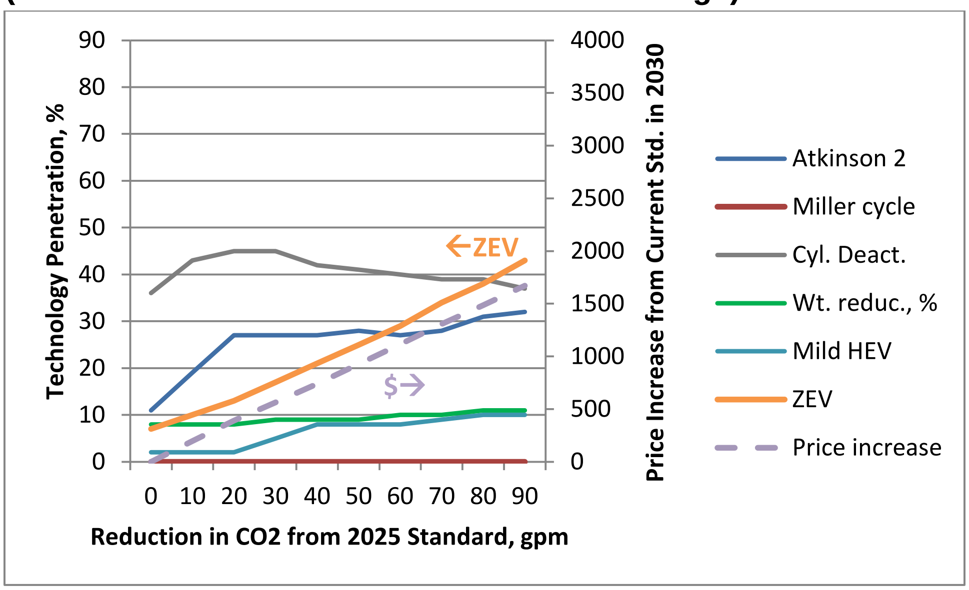
We evaluated CO_2 reduction targets 10 to 90 grams per mile (gpm) lower than the current 2025 standard, in 10 gpm increments. This enables determination of the technologies and price increase associated with any CO_2 reduction within this range.

We evaluated a number of scenarios using the EPA OMEGA model. We only modified the OMEGA model as necessary to allow it to project outcomes beyond 2025, and to evaluate different scenarios. The scenarios we created varied the number and types of ZEVs the model will consider, and varied the cost of manufacturing a ZEV using either the EPA or ICCT's cost estimates. The changes made to the OMEGA model are discussed in more detail in Section V and the Appendix.

Figure ES-1 shows a summary of the results for one scenario where the model is allowed to only select a BEV100 (a BEV with a 100 mile driving range based on the EPA label) when it is the most cost effective choice to further reduce CO_2 emissions.[6] This scenario also uses ICCT's lower ZEV manufacturing costs.

FIGURE ES-1

Technologies Needed to Achieve CO_2 Reductions in 2030*
(ICCT ZEV Costs and BEVs with 100 Mile Range)



*Solid lines refer to technology penetration (left Y axis). Dashed line refers to price increase (right Y axis) without accounting for fuel cost savings.

The figure above shows some of the technologies needed to achieve CO_2reductions of 10 to 90 gpm in 2030. In this scenario, the favorable price of a BEV100, which includes an additional $1,300 for a home charger and installation, is found more cost effective for many vehicle types than some of the conventional technologies such as Miller cycle engines and mild 48 volt hybrids. As a result, the percent of sales that are ZEVs in the least cost pathway needed to

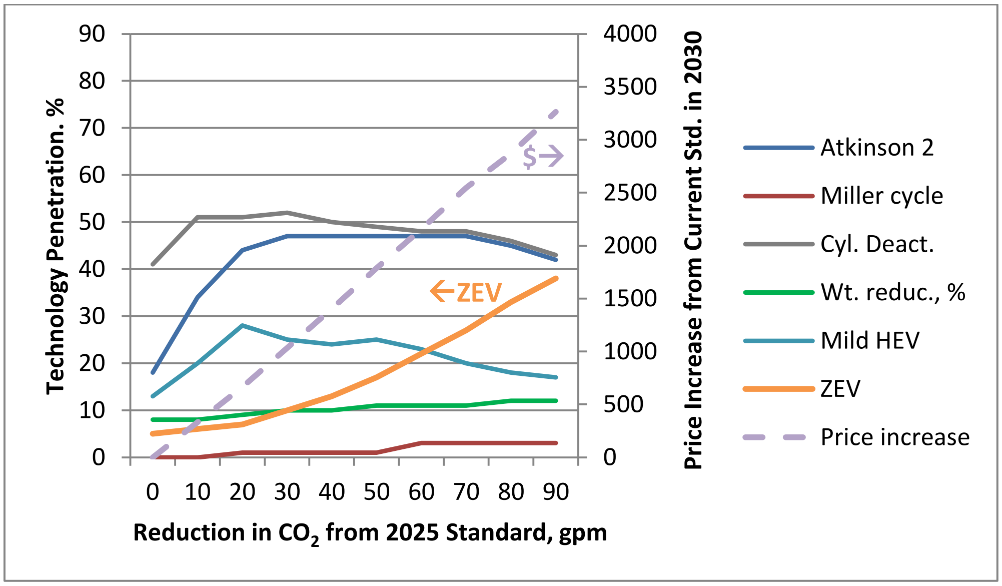
[6] The model selects a 100 mile BEV instead of longer range BEVs or PHEVs because the 100 mile ZEV is the most cost effective choice available. Note that no ZEVs are considered viable by the OMEGA model for vehicles capable of heavy towing (11% of vehicle sales).

reduce CO_2 by 50 gpm and 90 gpm below the current 2025 standard are 25 percent and 43 percent respectively in 2030. The manufacturer specific analysis of the OMEGA model also shows that all vehicle manufacturers (OEMs) have available technology that would enable them to achieve the 90 gpm target despite the variety of vehicle types they sell.

Figure ES-2 shows results of a similar scenario in which the only BEV the OMEGA model can select is a more expensive, longer range BEV200.[7]

Figure ES-2

Technologies Needed to Achieve CO_2 Reductions in 2030* (ICCT ZEV Costs and BEVs with 200 Mile Range)



*Solid lines refer to technology penetration (left Y axis). Dashed line refers to price increase (right Y axis) without accounting for fuel cost savings.

In this scenario the least cost pathway includes a larger proportion of conventional technologies and fewer ZEVs, compared to the previous BEV100 scenario. This is because more of the conventional technologies are cost effective, compared to the higher priced BEV200. The higher price of the BEV200 (which still accounts for 17 percent of sales at a 50 gpm CO_2 reduction, and 38 percent of sales at a 90 gpm reduction) results in a price per average vehicle that is $900 to $1,600 higher than in the BEV100 scenario; these cost analyses do not account for consumer savings in fuel prices. As in the BEV100 scenario, the OMEGA model shows that all vehicle manufacturers (OEMs) can technically achieve the 90 gpm target despite the variety of vehicle types they sell.

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[7] OMEGA was designed to find the lowest cost pathway to achieve reduced CO2 emissions, based on use of available technologies. It does not consider consumer preference in determining the pathway. We have evaluated both BEV100 and BEV200 scenarios in order to bracket the marketplace where it is likely both shorter and longer range BEVs will be present in the fleet.

The following table summarizes information from these two figures. It also includes an additional row which averages the penetration of BEV100s with BEV200s to represent a likely scenario where both types of BEVs are popular with consumers.

TABLE ES-1

Summary Results of Several Scenarios Evaluated

ZEV Penetrations

Scenario, Technology Penetration	CO2 Reduction Achieved*, gpm	ZEVs Sales Needed*, %
BEV100s only, ICCT $	50	25
	90	43
BEV200s only, ICCT $	50	17
	90	38
BEV100 & 200, ICCT $	50	21
(50% each)	90	40

Consumer Perspective: Price Impacts, Fuel Savings and Payback Periods**

Scenario BEV100 and BEV200 - 50% each	Increased Vehicle Price*, $	Lifetime Fuel Savings, $	Payback Period, yrs.
50 gpm CO2 reduction	**1350**	**3860**	**5.3**
90 gpm CO2 reduction	**2500**	**6855**	**5.3**

*Compared to current 2025 CO_2 standard assuming it is unchanged in 2030. ZEV sales and price increases (rounded) are for the CO2 gpm reduction listed. ZEV penetration includes 6 percent in the 2030 baseline.

**3% discount rate. Energy costs for 2030 are the same as used in the TAR

In summary, the availability of ZEV technologies opens a technological pathway for all OEMs to achieve large CO_2 emissions reductions by 2030. Achieving large reductions of CO_2 will necessitate a significant increase in the sale of ZEVs. ZEV market acceptance will, in turn, depend on model availability, price, supporting infrastructure, and other factors.

Statements from several vehicle manufacturers indicate a significant increase in ZEV models available by 2020, and projections that ZEV sales may account for 15 to 25 percent of their new vehicle sales by 2025. If this rate of growth continues, 40 percent ZEV sales by the 2030 timeframe is possible. As shown in Section V (Figure 7), this rate of growth of ZEV sales would be necessary to achieve a climate goal of 80 percent CO_2 emission reduction from the in-use passenger vehicle fleet wide by 2050.

The average price of a new 2030 model vehicle that achieves a 50 gpm reduction in CO_2 would increase by about $1350 (before considering fuel savings), compared to the 2025 standard. This is 1.5 times the vehicle price increase that will result from meeting the current 2025 CO_2 standard, compared to 2021 (the period subject to the MTE). A 50 gpm reduction also results in about 1.5 times the CO_2 emission reduction compared to the 2022 to 2025 reduction.

Achieving a larger 90 gpm CO_2 reduction would increase the average price of a 2030 model by about $2500 (before considering fuel savings), compared to the 2025 standard. This is about 3 times the price increase that will result from meeting the 2025 CO_2 standard, compared to 2021, and provides about 3 times the CO_2 reduction. In general, the cost of reducing CO_2 emissions increases in proportion to the emission reductions achieved, indicating that cost effectiveness remains relatively stable as greater reductions are achieved (within the 90 gpm range of reduction we evaluated).

As shown in Table ES-1, lifetime fuel savings will exceed the increased average vehicle price by a factor of nearly three. The breakeven point where fuel savings fully offset the higher vehicle price is about 5 years for both levels of CO_2 reduction (3 percent discount). The average period of ownership of a new passenger vehicle is 6.5 years. Over the lifetime of the 2026 to 2030 model vehicles, consumption of three billion barrels of oil would be avoided (90 gpm CO_2 reduction scenario).

Between 2025 and 2030, the number of ZEVs sales would have to increase by about 28 percent each year compared to the previous model year to achieve a 50 gpm CO_2 reduction in 2030. The year-on-year ZEV sales increase to achieve a 90 gpm CO_2 reduction would be 46 percent.

There are implications of these findings that are discussed at the end of Section V. Limitations of our modeling are also presented. We note that ICCT is also evaluating and updating the inputs to OMEGA, and is expected to issue a report in the first half of 2017. In particular ICCT is expected to update the effectiveness and the cost of several conventional technologies, and include in their analysis several other emerging technologies such as dynamic cylinder deactivation.

Section VI discusses several policy issues that should be examined when considering further reductions in CO_2 emissions.

We are not recommending regulatory adoption of specific CO_2 emission standards for 2026 and beyond. Additional technical and economic analyses, and input from all interested stakeholders, are necessary prior to adoption of new regulatory standards. The purpose of the report is to provide quantification of what CO_2 reductions may be possible, and the vehicle cost and the overall cost savings to customers when fuel savings are considered, with the hope it will help initiate and facilitate future analysis and discussion.

I. Purpose and context

The purpose of this paper is to assess, based on publicly available information, feasible nationwide CO_2 emission levels that could be achieved by 2030 model year passenger vehicles. We have assumed from our review of the available technical documents the CO_2 standards for model years 2022 to 2025 do not need to be changed. This assumption is consistent with EPA's Final Determination issued in early January 2017 which found that the current MY 2022 through 2025 standards remain appropriate.

CARB will also review the need for changes to the California zero emission vehicle (ZEV) regulation during its MTE hearing scheduled for late March 2017. Based on announcements of a growing number of planned introductions of ZEVs over the next five years, and expected reductions in cost, we also assume that the outcome of the CARB MTE will be consistent with EPA's findings—that the current requirements are achievable, and no change in the current ZEV requirements (through 2025) will be necessary. These assumptions define the 2025 baseline we are using to evaluate the feasibility of further CO_2 emission reductions.

An implication of these completed and forthcoming findings is the current 2025 model year CO_2 standards and ZEV requirements can be strengthened for the model years beginning with 2026. In this paper we evaluate the potential for greater use of conventional technologies[8], and the plausible growth in sales of ZEVs, to assess their possible role in further reducing CO_2 emissions.

The results of these evaluations are used to explore a range of possible CO_2 emission levels that may be achievable by new vehicles in the 2030 model year. Also considered is whether the growth of ZEVs and possibly other near-zero and zero emission vehicles in the years following 2030 would be on track to achieve at least an 80 percent reduction in the fleet of on-road passenger vehicle CO_2 emissions by 2050. CARB projects achieving this goal will require nearly 100 percent sales of ZEVs by 2050.

The information and the tools available to the public to evaluate the optimum CO_2 levels and ZEV requirements in the 2030 time frame reflect a portion of the analyses that government regulators would undertake in developing standards. Accordingly, we emphasize that this analysis represents a technical and economic assessment of feasible emission reductions but does not recommend specific policy outcomes or evaluate the full range of rulemaking considerations. We do believe that this report will help inform that process and specifically the dialogue associated with the development of post-2025 CO_2 standards.

To adopt by regulation further reductions in CO_2 emissions and revised ZEV requirements for 2030 models (the time frame we are evaluating), a strengthening of requirements would need to begin in the 2026 model year. This suggests new regulations would need to be adopted over the next few years in order to provide sufficient lead time for product development and the new car market to incorporate new technologies such as ZEVs in growing numbers. To meet this

[8] We define "conventional technologies" as technologies used on some vehicles today, or projected to be used by 2025, including non-plug-in hybrids. Conventional technologies do not include ZEVs which are defined as battery electric vehicles, plug-in hybrid electric vehicles, and fuel cell electric vehicles.

timeframe, regulatory development including technical workshops and stakeholder outreach should begin soon. For CARB this could be by mid-2017. The complexity of future standards, the lead time required, and the need to address ideas and concerns of many stakeholders means any delay in starting the rulemaking process could result in delayed realization of CO_2 emission reductions for model year 2026 and beyond.

This paper also assesses the adequacy of current policies and policy design structure to support more robust standards in 2026 and beyond. Issues include accommodating growing sales of ZEVs, integrating California ZEV requirements with national CO_2 standards, expanding refueling infrastructure for non-petroleum fueled vehicles, reducing upstream (well-to-tank) emissions, and accommodating mobility transformation such as vehicle sharing and autonomous vehicles. The value of fully evaluating these policy issues reinforces the benefit of initiating a rulemaking process that begins soon.

II. Climate goal and implications for future vehicle technologies

The Fifth Assessment Report of the Intergovernmental Panel on Climate Change made it clear: Warming of the climate system is unequivocal, changes in the climate have and will continue to impact natural and human systems around the world, and human influence on the climate system is clear.

The report also identified the mitigation needed to limit the surface warming to 2°C (450 ppm CO_2e) by 2100, compared to pre-industrial levels (0.6°C increase had already occurred by 2010). The 2°C temperature rise is a science-based target to limit warming, beyond which the risk of severe and irreversible impacts to the climate increases from moderate risk to high risk. Global-wide anthropogenic reductions in GHG emissions of 40 to 70 percent by 2050, and near zero emissions or below by 2100, are necessary to limit surface temperature rise to 2°C.

Many national and sub-national governments, such as California, have adopted an economy-wide 80 percent CO_2 emission reduction goal by 2050. In achieving this economy-wide goal, certain sectors and subsectors may be able to deliver greater reductions than in others. For example, within the on-road transportation subsector, new emission reducing technologies and cleaner fuels are currently being commercialized, and these have the potential to achieve 80 percent or greater emission reductions by 2050. For other transportation subsectors such as ocean-going ships, approaches to reducing CO_2 emissions currently are more limited, and development and implementation of strategies to achieve deep reduction in emissions may take more time.

Thus with respect to the on-road fleet of passenger vehicles, achieving at least an 80 percent CO_2 reduction by 2050, with a target of zero emissions by 2100, are the goals we keep in mind and influence how we evaluate new passenger car CO_2 emission reductions and ZEV requirements for the future.

III. Availability of conventional technologies to reduce CO2 emissions

When the federal agencies and CARB issued the first Technical Assessment Report in late 2010, they concluded a 2025 CO_2 standard 20 g/mi more stringent than what was adopted a year and half latter was technically feasible, without extensive use of hybrid or plug-in vehicles. In the final rule for the 2025 CO_2 standards, an updated sensitivity analysis reached the same conclusion.

The updated TAR prepared for the mid-term review and EPA's Preliminary Determination (PD) issued in November 2016 demonstrate the adopted CO_2 standard for 2025 is feasible and cost effective. EPA's Final Determination (FD) issued in January, 2017 concludes the 2022-25 standards remain appropriate.

These reports also indicate that numerous conventional technologies will not be fully utilized by vehicle manufacturers to comply with the 2025 standards. In additional to underutilized conventional technologies, the PD and FD also identify several emerging conventional technologies that were not considered in the EPA feasibility analysis for 2025 that are expected to be available to provide additional CO_2 reduction by 2025. This means that additional CO_2 reductions could occur beyond those currently required by regulation through the greater use of these current and emerging conventional technologies. In this section we further explore this opportunity and how it can contribute to achieving lower CO_2 emissions in the 2030 time frame.

First we look at the 2016 PD and FD to identify which currently available technologies are projected to be underutilized in meeting the current 2025 CO_2 emission standards. The OMEGA model used by EPA selects technology packages that reduce emissions sufficiently to meet a targeted CO_2 level (in this case the current 2025 CO_2 standards), based on the most cost effective approach. In some cases, such as low rolling resistance tires, variable valve timing and advanced transmissions, nearly 100 percent of vehicles are expected to use of these technologies by 2025. Other conventional technologies are expected to be significantly underutilized in 2025 models, and some of these are shown in Table 1. Their greater use would further reduce CO_2 emissions below the current 2025 standard.

TABLE 1

CO_2 Reduction Technologies Underutilized in 2025 Models

Technology	% Utilized in 2025[a]
Mass reduction	9[b]
Turbo, downsized engine	34
Off-cycle technologies	26
Atkinson cycle, non-turbo	25
Start-stop	15
Mild HEV (48 volt)	18
Full HEV (non-plug-in)	2

[a]Most of the technologies individually provide a single digit percentage reduction in CO_2 reduction. Individual technologies are combined into packages for use in OMEGA, and the packages may result in greater reductions.
[b]9% represents a fleet-wide average mass reduction, and not that 9% of vehicles used mass reduction.

As illustrated by the table, there are numerous commercially available conventional technologies whose greater use on 2026 and later models would further reduce CO_2 emissions.

In addition, it can be expected that technologies not currently deemed commercial will become available over the next decade. As an example of how quickly new technologies become commercial, the FD projects a quarter of 2025 model vehicles will use an advanced Atkinson cycle internal combustion engine, a technology not considered for widespread use in the first TAR issued just five years prior.

The FD discusses other emerging technologies such as Dynamic Cylinder Deactivation (DCD). This technology is not included in the FD modeling used to assess the 2025 CO_2 standards, or in our modeling discussed in Section V. DCD is reported to reduce CO_2 emissions between 7 and 10 percent, compared to 4 percent CO_2 reduction used in EPA's analysis for conventional cylinder deactivation.[9]

In Section V, we use the EPA's OMEGA model to determine how much additional CO_2 reduction is achievable in 2030 by greater use of conventional technologies in the absence of ZEVs. We then evaluate their role when ZEVs are also available to further reduce CO_2 emissions.

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[9] *See Delphi's Multi-Domain Mindset*, AUTOMOTIVE ENGINEERING, October 6, 2016, at 24. See also comments on the Proposed Determination submitted by the International Council on Clean Transportation (ICCT) at 4-5, Doc. ID: EPA-HQ-OAR-2015-0827-6108, *available at* https://www.regulations.gov/document?D=EPA-HQ-OAR-2015-0827-6108.

IV. Prospects for expanded sales of ZEVs

The status quo

Sales of plug-in electric (BEV and PHEV) and fuel cell vehicles for 2016 account for about 0.9 percent of national passenger vehicle sales, up 35 percent from 2015. California sales through November 2016 were 3.3 percent.

Most current ZEVs are available at favorable lease prices that are comparable to similar conventional vehicles. A federal tax credit is available, as are additional financial incentives in some states. For plug-in electric vehicles the cost of fueling the vehicle is also much lower. Also some states allow access to the high occupancy vehicle lanes for single driver ZEVs, and this has been shown to increase sales.

Many models are not currently available nationwide. For example, California buyers could select from 22 ZEV models in 2015; the next highest number of ZEV models available for sale in other states was 14 in New York, New Jersey, and Oregon. Nine states had zero or one ZEV model available, and eight more states had 2 to 4 models available for sale. Even in states outside of California that had a larger selection of models available, only slightly more than half the dealers in those states offered a ZEV for sale.[10]

In addition to the current relatively low availability of ZEVs, some other factors limiting ZEV sales are a lack of consumer awareness, low driving range of BEVs, and uncertainty about charging or refueling options. Another factor is the currently available ZEV models may not coincide with the consumers' needs or desires. For example, in 2016, 27 of 31 model ZEVs are sedans, a sector of the market that is not as popular as smaller SUVs and pick-up trucks. Only four ZEV SUVs were available, and no ZEV pick-up trucks.[11]

Will the market for ZEVs grow?

Numerous organizations project future sales of ZEVs. For 2020, the median sales of plug-in vehicles in the US is expected to be 8 percent, based on individual estimates of 7 organizations.[12] The range is 1 to 11 percent.

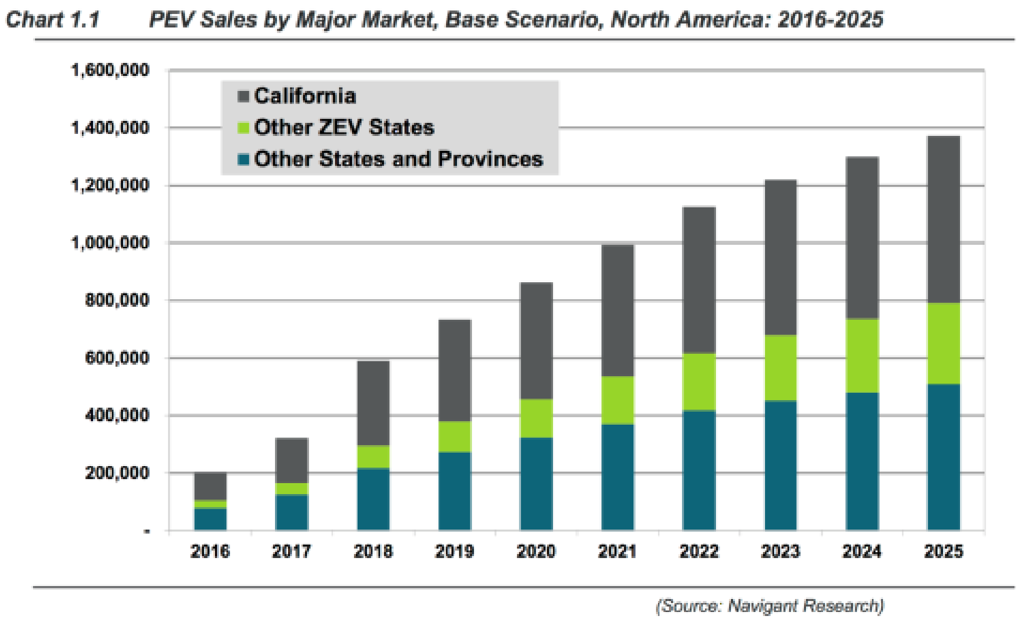
In June 2016, Navigant Research forecasted that ZEVs annual sales in the US and Canada will increase from 200,000 in 2016 to nearly 1.4 million by 2025, an increase of a factor of seven. As a percentage of all passenger vehicle sales, new ZEV sales are forecasted to be about 7 percent nationally and about 27 percent in California in 2025. Bloomberg New Energy Finance forecasts

[10] Union of Concerned Scientists, *Electrifying the Vehicle Market*, August 2016, *available at* www.ucsusa.org/EVAvailability.
[11] Inside EVs, Monthly Plug-In Sales Scorecard, http://insideevs.com/monthly-plug-in-sales-scorecard/ (last visited February 23, 2017).
[12] Stephen Edelstein, *Electric-Car Market Share in 2020: Estimates Vary Widely* (January 2, 2017), http://www.greencarreports.com/news/1108087_electric-car-market-share-in-2020-estimates-vary-widely.

a rapid growth of worldwide ZEV annual sales to nearly 20 percent in 2030 and 35 percent in 2040.[13]

FIGURE 1

Projected Plug-in Passenger Vehicle Sales in US and Canada



Some vehicle manufacturers have recently offered projections of future sales of their ZEVs. Three major European automobile manufacturers with a US presence have publicly stated they expect 15 to 25 percent of their worldwide sales in 2025 to be electric vehicles.[14] While these suggested volumes may at this time be aspirational, these manufacturers have shared specific plans for introduction of a variety of new ZEV models. VW has suggested it will offer 30 new pure electric models by 2025, Mercedes Benz 10, and BMW an expansion of its "i-series" and transfer of its electric technology to all of its main BMW and Mini products.

These statements indicate a large investment in ZEV vehicles is underway, and suggest these manufacturers are planning for electric drive vehicles to become a rapidly growing part of their future product offerings. Rationales offered for OEMs making a shift to electric drive include the importance of addressing climate change (e.g. the Paris agreement) and associated government policies to reduce GHG emissions (e.g. China, EU and the USA), restrictions on

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[13]Bloomberg, The Rise of Electric Cars (February 25, 2016), http://www.bloomberg.com/features/2016-ev-oil-crisis/img/ev-sales.jpg.

[14]Kirsten Korosec, *Volkswagen's Future Includes 30 New Electric Vehicles and Self-Driving Taxis*, FORTUNE, June 16, 2016, *available at* http://fortune.com/2016/06/16/volkswagen-2025-electric-future/ ; Elisabeth Behrmann, *Mercedes EQ Brand Plans 10 Models to Take on Tesla*, BLOOMBERG, September 29, 2016, http://www.bloomberg.com/news/articles/2016-09-29/mercedes-plans-10-electric-cars-under-eq-brand-to-take-on-tesla; Elisabeth Behrmann and Matt Miller, *BMW Sees Electric Cars Pushing Into Mainstream in Tesla Race*, BLOOMBERG, October 11, 2016, http://www.bloomberg.com/news/articles/2016-10-11/bmw-ceo-sees-electric-cars-pushing-into-mainstream-in-tesla-race.

driving combustion engine vehicles in dense centers of some large cities, the emergence of new mobility technologies such as autonomous vehicles and ridesharing in which electric vehicles may provide a role, competition with new electric vehicle producers such as Tesla, lower operating cost, and uncertainty in the future role of diesel passenger cars.

Another approach for assessing the future is to look at some of the underlying trends that could affect future sales, and then evaluate if these trends support a growing market for ZEVs.

Number of models

First we look at the number of models available now and likely to become available within the next five years, as an indicator of future growth of the market for ZEVs. Although announcements of models to be introduced beyond 2020 are scarce, a significant number of model introductions in the next four years would indicate a large investment and commitment by vehicle manufacturers to commercialize ZEVs as a sustainable technology for reducing CO_2 emissions.

Table 2 indicates the significant growth in number of ZEV models expected to be available by 2020. Unlike many publicly available summaries of future ZEV introductions that include all models, this table only includes those models likely to be mass marketed that also contribute substantially to lower CO_2 emissions. Specifically we have included only models with the potential of large volume sales, using the criterion their price (MSRP) is expected to be under $60,000. We have also excluded from the table PHEVs with electric range 20 miles or less. While PHEVs with a relatively small electric range may capture market share, recent data indicate a 20 mile PHEV operates on electricity only about 30 percent of the miles traveled.[15] Its dependence on using gasoline to accomplish many driving tasks[16] dilutes its environmental benefit and makes PHEVs a less viable long term solution to achieve the climate goals discussed in Section II. Table 2 reflects growth in the number of new BEV, FCEV and longer range PHEV models announced for introduction in the next four years.

TABLE 2

Number of ZEV Models Expected to Be Available by 2020[17]

Current ZEV Models (mid-2016)	Announced ZEV Models by 2020
11	32

As shown in the table, the number of ZEV models expected to be available for purchase by the end of 2020 nearly triples compared to the number available today. The diversity of models expands to include more SUVs, numerous high performance cars (not included in the table due to likely limited production), and possibly a smaller pick-up truck. The rapid expansion of

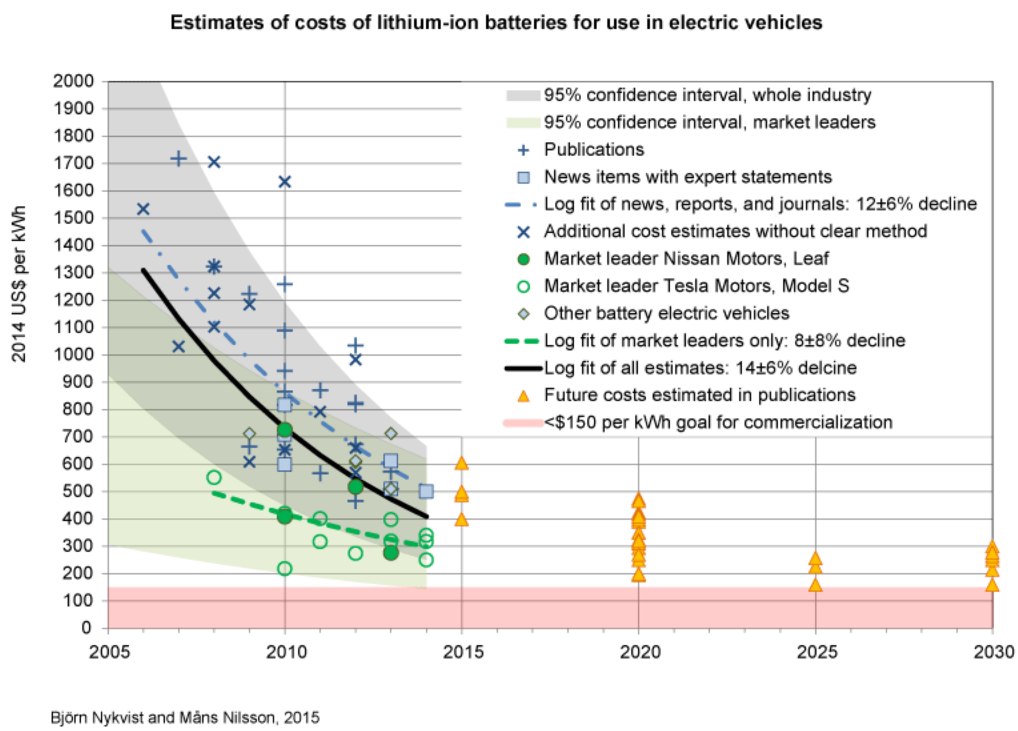
[15]Ryan Hart, California Air Resources Board, Analysis of Plug-in Electric Vehicle Usage (September 27, 2016), *available at* https://www.arb.ca.gov/msprog/consumer_info/advanced_clean_cars/oem_pev_driving_and_charging_characteristics_ryan_hart.pdf.
[16] The average driving distance per car per day is 29 miles (US Bureau of Statistics).
[17] Assumptions: Expected price <$60K; electric range for PHEV >20 miles; includes the 12 manufacturers subject to CA ZEV mandate, and Tesla lower priced models. Data as of September, 2016: Frequent new announcements may significantly change the number of 2020 models shown in the table.

models is consistent with an expectation of a growing market for ZEVs in 2020 and beyond. The large investment by OEMs suggests more of these models will become available in states outside of California as well.

Battery cost – Although many current ZEVs can be leased for a favorable monthly payment, the low production volume and high development cost of currently available models suggests the lease price, and the suggested retail price, are less than the manufacturer's cost. Increased production volume, continued technical and manufacturing innovation, and an expanding supplier base, will drive down manufacturing costs. This raises the question of whether cost can be reduced enough to result in ZEVs being priced competitively with conventional passenger vehicles that are facing higher costs to meet increasingly protectiveCO_2 emission standards, by 2025 and likely beyond.

The most expensive component of a BEV or longer range PHEV is the battery. An often quoted 2015 study indicates the manufacturing cost of lithium ion battery packs has dropped by about 70 percent between 2007 and 2014. Figure 2 illustrates the declining cost of battery packs from this study.[18]

FIGURE 2
Battery Pack Manufacturing Costs



[18] Björn Nykvis and Måns Nilsson, Rapidly falling costs of battery packs for electric vehicles, 5 Nature Climate Change 329–332 (2015), *available at* http://www.nature.com/nclimate/journal/v5/n4/abs/nclimate2564.html.

More recent studies and announcements suggest even lower costs. GM has commented its battery cell cost could decline to $100/kWhr by 2022 (an adjusted pack cost would be $130/kWhr for a 150 mile range BEV, although this varies by pack size).[19] Ford recently reported its cell cost in 2030 is expected to be $85/kWhr, resulting in a $110/kWhr pack cost.[20]

A more detailed analysis of battery pack costs using Argonne National Laboratory's BatPaC model was published in EPA's Preliminary Determination on progress towards achieving the 2025 CO_2 emission standards for passenger vehicles. Table 3 presents some of the results from the EPA PD.[21]

TABLE 3

Battery Pack Manufacturing Cost in 2025, $/kWhr

Vehicle Type	BEV 200 mi[22]	BEV 100 mi	PHEV 40 mi.
Standard car	142	171	251
Small SUV	132	159	246
PU Truck	123	148	228

EPA's estimates of battery pack manufacturing cost based on BatPacC have dropped by about 15 percent for BEVs since its 2012 rulemaking adopting passenger vehicle CO_2 standards through model year 2025. Battery costs for PHEVs were unchanged. The results of the EPA BatPaC modeling and the GM and Ford announcements indicate by 2025 or soon thereafter the manufacturing cost of large battery packs will approach or meet the USDOE and USCAR goal of $125/kWhr.

<u>Vehicle cost</u>: Early this decade the incremental cost of ZEVs was estimated at roughly $10,000 higher than a conventional gasoline powered car in 2025, assuming relatively high production volumes.[23] Subsequently the NAS (2013) estimated the incremental cost of a BEV and PHEV compared to a gasoline vehicle in 2025 would be $5,000 and $4,000 respectively, and that a BEV would achieve cost parity with a conventional gasoline vehicle by 2045 (PHEVs would cost $2,000 more in 2050).[24]

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[19] Mary Barra, General Motors Global Business Conference, October 1, 2015.

[20] "Ford, Investor Day (September 14, 2016), *available at* https://corporate.ford.com/content/dam/corporate/en/investors/investor-events/Press%20Releases/2016/september-2016-ford-investor-deck-for-web.pdf.

[21] Proposed Determination on the Appropriateness of the Model Year 2022-2025 Light-Duty Vehicle Greenhouse Gas Emissions Standards under the Midterm Evaluation 2016, EPA-420-R-16-020, U.S. EPA, November 30, 2016.

[22] BEV 200 is a battery electric vehicle with an EPA label range of 200 miles.

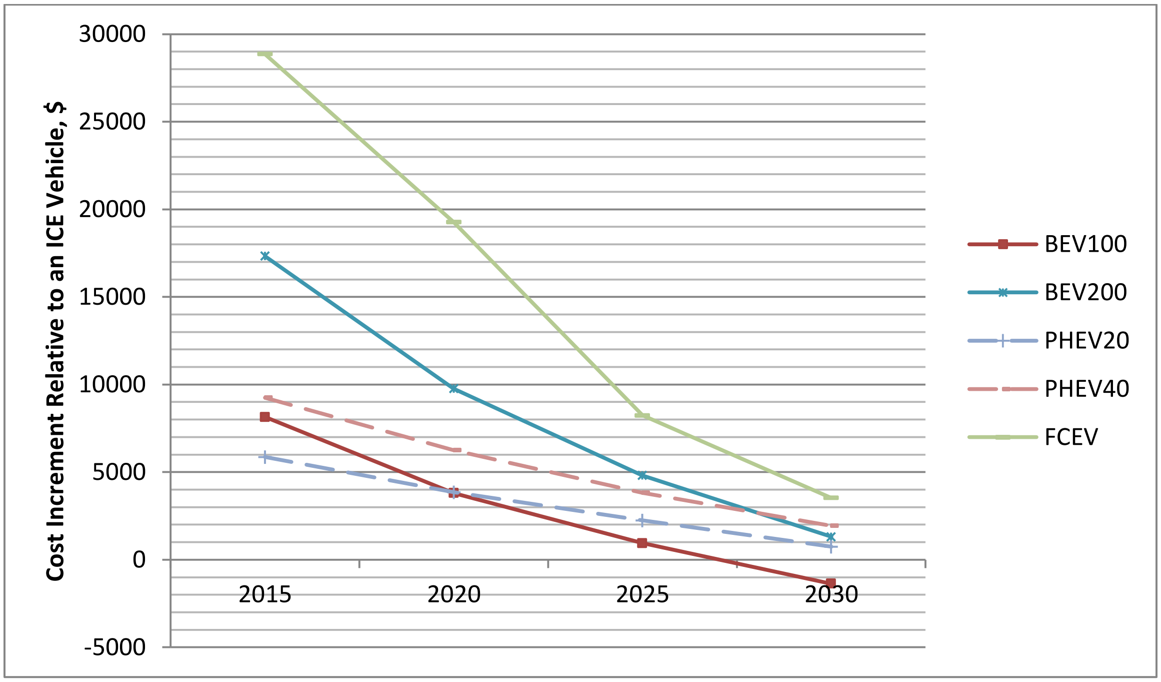
[23] California Air Resources Board, *Staff Report: Initial Statement of Reasons, 2012 Proposed Amendments to the California Zero Emission Vehicle Program Regulations* (December 2011), *available at* https://www.arb.ca.gov/regact/2012/zev2012/zevisor.pdf.

[24] National Research Council of the National Academies, Transitions to Alternative Vehicles and Fuels (2013) at 38, *available at* https://www.nap.edu/catalog/18264/transitions-to-alternative-vehicles-and-fuels.

ICCT published in 2016 a literature review of ZEV manufacturing costs and updated the cost estimates through 2030 of the electric componentry including the battery pack, to reflect the latest information. The results are shown in Figure 3.[25]

FIGURE 3

Incremental Manufacturing Cost of ZEVs, Relative to Gasoline Small Car in Same Year



ICCT's results show the dramatic drop in vehicle manufacturing costs due to lower cost electric components, relative to the increasing cost of a conventional internal combustion engine (ICE) vehicle (non-hybrid) of the same year. For example, a 100 mile BEV is projected to have a manufacturing cost more than $1000 below the cost of a comparable compact size car by 2030. A 200 mile BEV will cost about $1,300 more than an ICE in 2030, with costs likely to continue to decline after 2030. PHEV20s and 40s will be one to two thousand dollars more expensive than an ICE because of the cost of two motors – electric and ICE. FCEVs experience the greatest drop in manufacturing cost by 2030, but remain about $3,500 more costly than a 2030 model ICE vehicle. Most estimates of incremental manufacturing cost were much higher just five years ago, with no expectation of cost parity with ICEs in the near term. The rapidly declining cost of batteries and the increasing cost of achieving low CO_2 from ICEs are the main factors contributing to the projected lower costs of ZEVs relative to ICEs by 2030.

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[25] Paul Wolfram and Nic Lutsey, *Electric vehicles: Literature review of technology costs and carbon emissions*, International Council on Clean Transportation (ICCT) (July 15, 2016), available at http://www.theicct.org/sites/default/files/publications/ICCT_LitRvw_EV-tech-costs_201607.pdf. Data from Figure 8 converted to US dollars, range discounted from dyno test to on-road, and battery cost scaled to nearest EPA label-based range nomenclature (e.g. BEV 100).

Conclusion

Prospects for a large expansion of ZEVs into the marketplace by 2030 appear good. The main reason for this more optimistic outlook compared to the past is the cost of batteries and other electronic components are declining rapidly, and the manufacturing cost of a battery powered ZEV in the 2030 timeframe appears to be close to, and in some cases less than the cost of a conventional gasoline fueled passenger vehicle.

Vehicle manufacturers are rapidly expanding the number of ZEV models available, opening the door to market expansion. Many battery ZEVs are expected to have twice the range they have today (e.g. 238 mile range 2017 GM Bolt), which opens the primary car market to ZEVs. Fuel cell vehicles are entering the market, and their projected cost is also declining rapidly, providing another ZEV technology that may be particularly suitable for larger vehicles such as full size SUVs and pick-up trucks.

Fast charging for battery vehicles is expanding rapidly as well, allowing extended use of longer range BEVs. Longer range PHEVs, such as the 52 mile electric GM Volt Generation 2, can meet most urban driving needs on electricity, and use their range extender for longer trips, albeit using gasoline. The cost of vehicle operation (for battery vehicles) will be lower than conventional vehicles at any foreseeable price of gasoline.

V. CO_2 emission levels achievable in 2030

Background

As discussed in Sections III and IV, technologies are available to achieve lower CO_2 emissions from passenger vehicles in the post-2025 timeframe, compared to the existing 2025 standards. These include available and emerging conventional technologies whose widespread use is not expected to be necessary to comply with the 2025 emission standards. In addition, electric drive vehicles have achieved a presence in the passenger vehicle market, and their declining cost, expanding number of models available, and improving driving range point to greater acceptability and a growing market share.

We have used the EPA model OMEGA to evaluate the feasibility and price increase of achieving larger reductions in CO_2 emissions from passenger vehicles in the post-2025 time frame. OMEGA is the model EPA used in the 2012 GHG rule adoption, the most recent TAR and the Proposed and Final Determination to evaluate the adequacy of the CO_2 emission standards for 2022 to 2025 model years. OMEGA evaluates the relative cost and effectiveness of available technologies and determines the most cost effective technology pathway to achieve a particular CO_2 emission level. The model analyzes about 200 vehicle platforms which encompass approximately 1,300 vehicle models to capture important differences in vehicle and engine design and utility. A more in-depth description of the model, and how effectiveness and cost of technologies were determined, can be found in the TAR and PD.

We have used the latest version of this model (Version 1.4.56 and Pre-Processors made available by EPA in November 2016) to project the technologies needed to achieve lower CO_2 emissions from 2030 model passenger vehicles, and the impact on vehicle price and operating cost. OMEGA includes 80 individual technologies which are combined into thousands of technology packages considered feasible for use by various size vehicles. OMEGA adds technology packages to the vehicle models of each major vehicle manufacturer in order to achieve lower CO_2 emissions. It does this by evaluating the feasibility of each technical package for each manufacturer's models, the emission reductions available, and the upfront cost, and then selects the most cost effective technology package to achieve the next increment of CO_2 reduction.

We only made changes to the OMEGA model necessary to extend its modeling domain from 2025 to 2030. The basic changes we made were to add sales estimates for 2030, and increase the model's caps (limits) on use of various technologies (such as ZEVs). In the model, these caps limit the use of some technologies that are new or otherwise may not be able to be widely utilized by 2025. OMEGA increases these caps over time; for example from 2021 to 2025. We extended the caps linearly to 2030. In most cases this eliminated the cap (i.e. the technology was considered feasible for most vehicles by 2030.) For ZEV technologies which EPA capped at relatively low volumes, we modified the caps in order to evaluate different scenarios. Other than these changes, and changes to facilitate analyzing specific scenarios as described below (e.g. a no ZEV growth scenario, and use of lower ZEV manufacturing costs), the model was run consistent with the way it was run by EPA for the PD.

We created seven scenarios to evaluate the CO_2 reductions possible, with varying modeling assumptions. Three scenarios used EPA cost estimates for ZEVs, with varying caps on the number or type of ZEVs from which the model could select. The three variations in ZEV caps included: Those specified by EPA in the TAR; allowing only BEV100s to be selected; and allowing only BEV200s to be selected by the model in determining the most cost effective pathway to achieving a specified emission reduction.[26] These three scenarios were also repeated using lower ZEV manufacturing costs than used by EPA, based on a recent report provided by ICCT (see Table 4 and additional discussion in Section IV). The seventh scenario prevented the model from selecting any ZEVs beyond those in the baseline, and is used to determine the CO2 reductions achievable and the resulting vehicle average price increase due to use of only conventional (non-ZEV) technologies. More details on the changes we made, and the scenarios we evaluated, can be found in the Appendix.

Results

In the remainder of this section we present the results of three of our OMEGA modeling runs, and evaluate each scenario with the objective of estimating how much vehicle CO_2 reduction can be technically achieved in 2030. The results of all seven scenarios can be found in the Appendix. To evaluate various reduction stringencies, in each scenario we set CO_2 targets ranging from 10 to 90 gpm reduction in tailpipe CO_2 emissions for the combined car and truck fleet consisting of all manufacturers, and compare the results to the current 2025 standards extended to year 2030. This enables an assessment of the technologies and incremental upfront price for a range of CO_2 reductions. For reference, the current 2025 standard using the current national sales mix of cars and trucks is about 173 gpm.[27]

Based on these scenarios we suggest CO_2 reductions from new passenger cars that could be achieved in 2030 taking into account the incremental upfront cost, and feasibility of compliance for individual vehicle manufacturers. Our conclusions are discussed at the end of this section and in the Executive Summary.

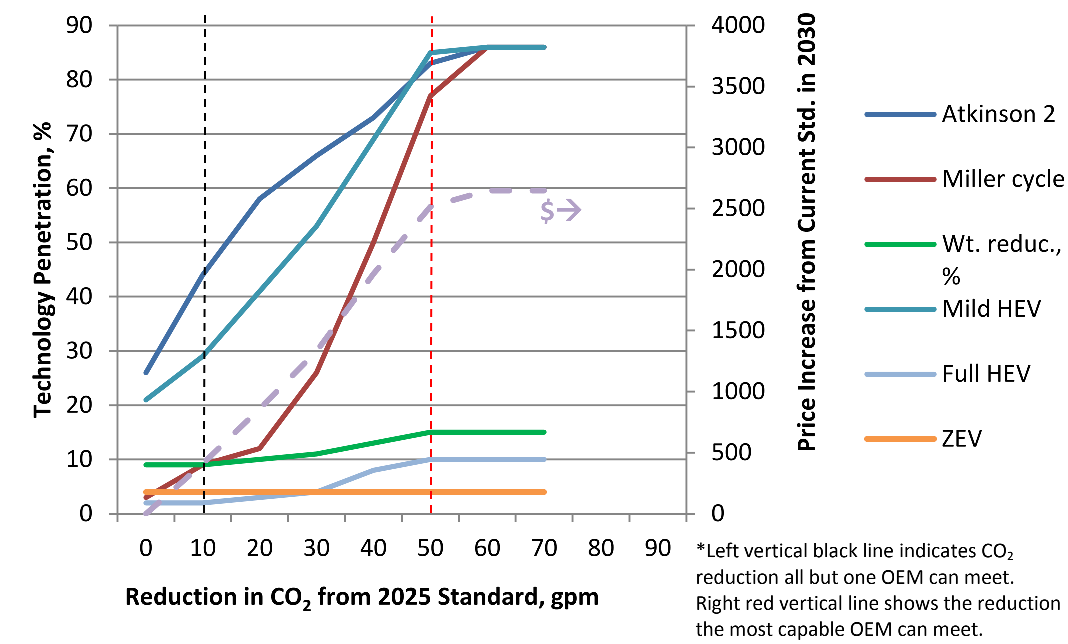
We first address the question: *How much* CO_2 *reduction can be achieved by relying only on currently available conventional technologies; and its corollary: Are ZEVs needed to achieve significant* CO_2 *reductions by 2030?* We zero out any growth in ZEV sales in the OMEGA model, beyond the small number of ZEVs already in the projected 2025 baseline used by EPA in the PD. The results are presented in Figure 4.

[26] In all scenarios, no ZEVs are allowed to be selected for heavy-towing capable vehicles (about 11 percent of sales), which is a limitation used by EPA in the PD and FD.

[27] The often referenced 163 gpm 2025 CO_2 fleet average standard presented in the 2012 EPA final rulemaking was based on a higher fraction of cars compared to light trucks, than is currently the case. Also note that the absolute gpm values (such as 173 gpm) we use in the report include a constant non-tailpipe GHG reduction of 23 gpm.

FIGURE 4

Technologies Needed to Achieve CO_2 Reductions in 2030, If No ZEVs Are Available After 2025*



*Left vertical black line indicates CO_2 reduction all but one OEM can meet. Right red vertical line shows the reduction the most capable OEM can meet.

As shown in Figure 4, conventional technologies such as mild hybrids, Atkinson and Miller cycle engines, which are projected to be underutilized in meeting the 2025 standard, are rapidly adopted to meet increasingly stringent CO_2 targets in 2030. (This and the following figures only show a few of the technologies whose use was evaluated.) Weight reduction is maximized to the limit imposed by the OMEGA model based on current safety considerations. Full HEVs only grow to about 10% of sales because for all but a few vehicle types, the technology packages containing mild hybrids provide slightly larger emission reductions at lower cost compared to a full HEV (see discussion in the Appendix). Thus using more full HEVs would not result in greater emission reductions.

When only conventional technologies are available to reduce CO_2 emissions, the average fleet vehicle begins falling short of the CO_2 reduction target at about 30 gpm reduction.

Not all manufacturers (OEMs) are able to utilize these conventional technologies to the same degree and effectiveness. One OEM fails to achieve 10 gpm CO_2 reduction using all available conventional technologies. Two more OEMs fail to achieve a 20 gpm reduction. No manufacturer achieves a 60 gpm reduction target. As discussed in Section III, there are several emerging technologies that will likely be available by 2026 whose use may achieve additional CO_2 reduction; however these technologies are not included in the current OMEGA model. Thus we conclude that in the absence of ZEVs in the marketplace from 2025 to 2030, CO_2 reductions of 10 to 30 gpm will be achievable by most if not all OEMs using the best conventional technologies. To achieve larger CO_2 reductions, most OEMs will need to rely on ZEV technologies.

Feasibility and cost of achieving greater CO_2 emission reductions with ZEVs

To determine the benefits and incremental price increase, we remove the prior modeling restriction on selecting ZEVs and allow the model to select a ZEV when it is the most cost effective choice to reach the next increment of CO_2 reduction. OMEGA will always pick a short range BEV first because its cost is lowest and all BEVs are recognized as having zero CO_2 emissions.

To explore the impact on CO_2 reduction and average vehicle price increase of various types of BEVs, we force the model to select only one type (driving range) BEV at a time. We start by allowing the model to only recognize a 100 mile range BEV100 as an available technology to reduce CO_2. Then we run the model again allowing it to recognize only 200 mile BEV200s. This allows us to bracket the fleet average price increase when in the real world ZEVs with varying ranges and prices are expected to be purchased.[28]

For these two scenarios we also replace EPA's conservative estimate of the cost of ZEV technologies with a lower projected cost based on the recent ICCT study, as discussed in Section IV. The table below compares the incremental manufacturing cost for several types of small car ZEVs as used by EPA in the PD with costs from the ICCT report. We created estimates of ZEV manufacturing costs for all the vehicle classes used in OMEGA, by scaling the information in the ICCT report (see the Appendix for methodology).

TABLE 4

Comparison of Incremental Manufacturing Cost for ZEVs In 2030 vs 2010 Baseline, Small Car

Type of ZEV	EPA PD $	ICCT* $
BEV 100	4153	1073
BEV 200	5782	3709
PHEV 40	5361	4398

*ICCT used test range to identify the various types of ZEVs (e.g. BEV100). We adjusted ICCTs manufacturing costs to reflect real world vehicle range, to be consistent with EPA terminology. Note that we present retail price in Figures 4-6 of our report. Retail price includes a mark up from the manufacturing cost shown here, and the cost of a charger and installation for BEVs.

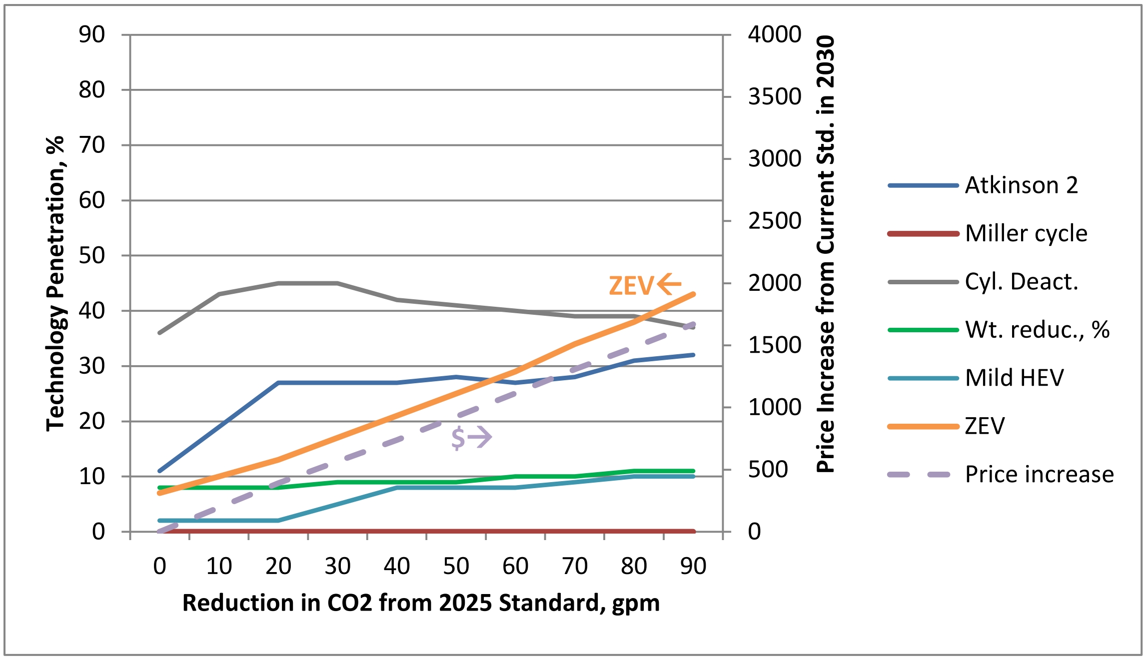
Figure 5 presents the results for the scenario where the only type of BEV considered available has a range of 100 miles. No cap is imposed by the model on how many BEV100s may be chosen by the model (other than no battery vehicles are allowed to be selected for vehicles with heavy-duty towing capacity). The model finds a pathway to a 90 gpm CO_2 reduction that is technically feasible for all manufacturers.

[28]OMEGA also includes 75 mile range BEVs, which are available for only two small vehicle classes. For simplicity we modified the model to prevent selection of 75 mile range BEVs. Also note that the model will not select PHEVs if a BEV is available because the BEVs achieve greater CO_2 reduction, and in many cases at a similar cost, and thus BEVs are the most cost effective choice.

For this BEV100 scenario, the fleet average vehicle price increase in 2030 for a 50 gpm CO_2 reduction is about $900 above the 2030 price for complying with the current 2025 standards. To achieve a 90 gpm CO_2 reduction, the incremental price increases to $1700. BEV100s account for 25 percent of sales when a 50 gpm reduction is achieved, and 43 percent for a 90 gpm reduction. The relatively low price of BEV100s is favorable compared to some applications of conventional technology, which as a result are used less frequently (Figure 5).

FIGURE 5

Technologies Needed to Achieve CO_2 Reductions in 2030* (ICCT ZEV Costs and Only BEV100s Available)

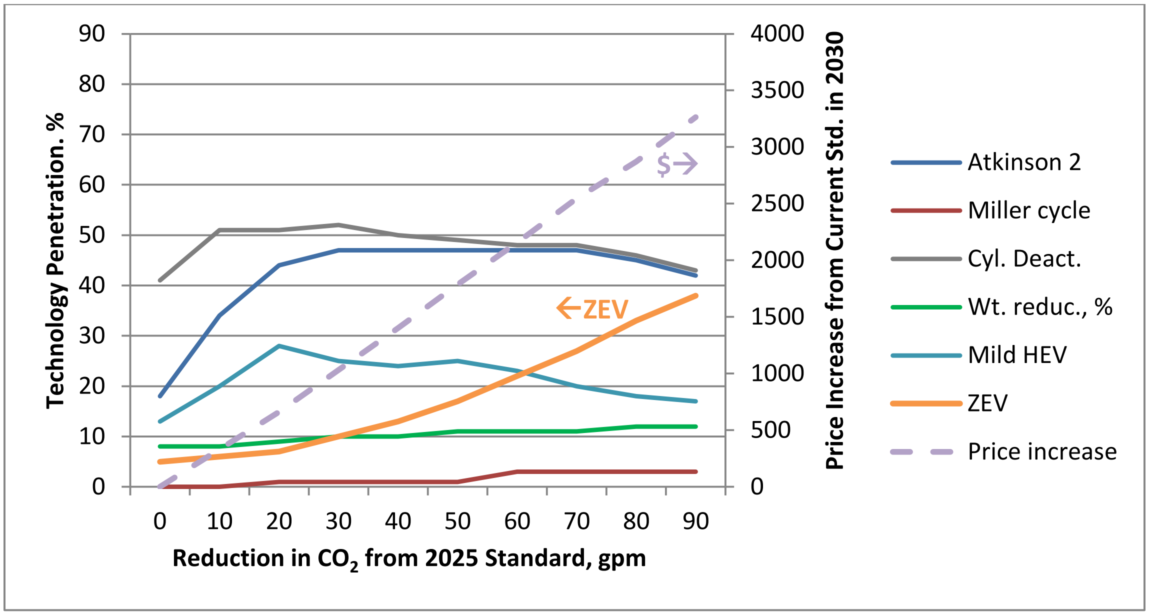


*Solid lines refer to technology penetration (left Y axis). Dashed line refers to price increase (right Y axis) without accounting for fuel cost savings.

In Figure 6 we present the same scenario shown in Figure 5, but change the type of BEV that is recognized by OMEGA to a longer range BEV200 (i.e. no BEV100s can be selected). In this scenario, the ZEV sales required to achieve a 50 gpm CO_2 reduction are 17 percent. To achieve a 90 gpm reduction, ZEV sales would need to increase to 38 percent. Because BEV200s have a higher price than BEV100s, more conventional technologies are found to be the cost effective choice. As a result the penetration of conventional technologies increases somewhat, and the sales percentage of BEV200s decreases, compared to the BEV100 scenario shown in Figure 5. The average fleet vehicle price is $900 higher for a 50 gpm reduction, and $1,600 higher for a 90 gpm CO_2 reduction, compared to the BEV100 scenario (neither scenario accounts for the fuel cost savings due to BEVs).

FIGURE 6

Technologies Needed to Achieve CO_2 Reductions in 2030* (ICCT ZEV Costs and Only BEV200s Available)



*Solid lines refer to technology penetration (left Y axis). Dashed line refers to price increase (right Y axis) without accounting for fuel cost savings.

Evaluation

Table 5 summarizes the CO_2 gpm reduction that can technically achieved by manufacturers in 2030, the percent ZEV sales required to achieve the CO_2 reduction, and the increased price for the average vehicle, for the three scenarios discussed above. Also included in the table is the average of the BEV100 and BEV200 scenarios to represent the case where both types of BEVs are in the market.

TABLE 5

Summary Results of Several Scenarios Evaluated

Scenario, Technology Penetration	CO2 Reduction Achieved*, gpm	ZEVs Sales Needed**, %	Price Increase*, Fleet Average, $
Conventional Technology only, no ZEVs	10	4	400
	30	4	1300
ZEVs: BEV100s only; ICCT ZEV costs	50	25	900
	90	43	1700
ZEVs: BEV200s only; ICCT ZEV costs	50	17	1800
	90	38	3300
ZEVs: BEV100 & 200 (50% each); ICCT ZEV costs	50	21	1350
	90	40	2500

*Compared to current CO_2 standards in 2030.

**Baseline 2030 ZEV sales are included in this column, thus the 4% sales in the conventional technology (no new ZEV sales) scenario.

The relevance of the Conventional Technology only, no ZEVs scenario is there is a limit on how much CO_2 reduction can be achieved using only commercially available conventional technology, and it is relatively small. ZEV technology is necessary to achieve CO_2 reductions beyond 30 gpm for most manufacturers.

The BEV100 and BEV200 scenarios, which do not restrict the number of ZEVs the model may select (except for heavy-duty towing capable vehicles), represent a more rigorous push to reduce CO_2 emissions from passenger vehicles in the 2030 time frame. The OMEGA modeling results for these BEV scenarios indicate a 90 gpm reduction in CO_2 emissions from 2030 models is technically feasible, compared to the current standard. If verified though a regulatory process, this could result in a CO2 standard of 83 gpm in 2030, compared to the 2025 standard of 173 gpm.

For context, a 50 and 90 gpm reduction in 2030 would be about 1.5 and 3 times greater than the 32 gpm CO_2 reduction in 2025 resulting from the last four years of the current standards that are the subject of the MTE.

The percentage of ZEVs sold in 2030 would need to be 21 percent (again averaging the results of the two BEV scenarios) to achieve a 50 gpm CO_2 reduction, and 40 percent to achieve a 90 gpm reduction. Between 2025 and 2030, the number of ZEVs sales would have to increase by about 28 percent each year compared to the previous model year to achieve a 50 gpm CO_2 reduction, and 46 percent per year to achieve a 90 gpm reduction. This significant increase in sales of ZEVs could reduce the need to apply advanced technologies to conventional vehicles because of the much larger reduction in CO_2 emissions resulting for each ZEV sold (see footnote in Section VI – One National Program, for further explanation). Looked at another way, a larger ZEV sales fraction could support a greater annual rate of progress in reducing CO_2 emissions because each ZEV reduces CO_2 emissions much more than is possible with improvements to a conventional vehicle.

The price for an average 2030 model would increase by about $1350 to reduce CO_2 by 50 gpm if we assume that an equal number of BEV100 and BEV200 vehicles are sold (average of the BEV100 and BEV 200 scenarios in Table 5) (without accounting for fuel cost savings). To achieve 90 gpm, the average price would increase by $2500 (again, without accounting for fuel cost savings).[29] These are about 1.5 and 3 times the price increase expected in 2025 compared to the 2021 standard. The CO_2 emission reductions are also about 1.5 and 3 times greater. Thus the cost effectiveness is relatively stable as greater CO_2 reductions are achieved.

As shown in Table 4, the ICCT direct manufacturing cost for a BEV100 is substantially lower than the EPA cost estimate. We estimated the sensitivity of doubling the ICCT incremental

[29] To assess the sensitivity of using ICCT's estimates of ZEV cost instead of EPAs, we ran the scenarios presented above using EPA's estimates of ZEV costs. For the combined BEV100/BEV200 scenario, the average vehicle price increase to achieve a 50 gpm and 90 gpm CO_2 reduction would increase by $500 and $900 respectively if EPA's higher ZEV cost estimates were used (these potential increases do not account for consumer fuel price savings).

manufacturing cost estimate for a BEV100 on fleet average price increase. The fleet average price increase for a 50 gpm and 90 gpm CO2 reduction would be about $150 and $300 higher respectively, compared to the prices shown in the last two rows of Table 5.

Table 6 presents the fuel savings and payback periods for a 50 and 90 gpm CO_2 reduction, for the scenario in which equal numbers of BEV100s and BEV200s are sold.

TABLE 6

Consumer Perspective: Fuel Savings and Payback Periods*, ICCT ZEV Costs

Scenario BEV100 and BEV200 - 50% each	Increased Vehicle Price, $	Lifetime Fuel Savings, $	Payback Period, yrs.
50 gpm CO_2 reduction	**1350**	**3860**	**5.3**
90 gpm CO_2 reduction	**2500**	**6855**	**5.3**

*3% discount rate. Energy costs same as used in the TAR

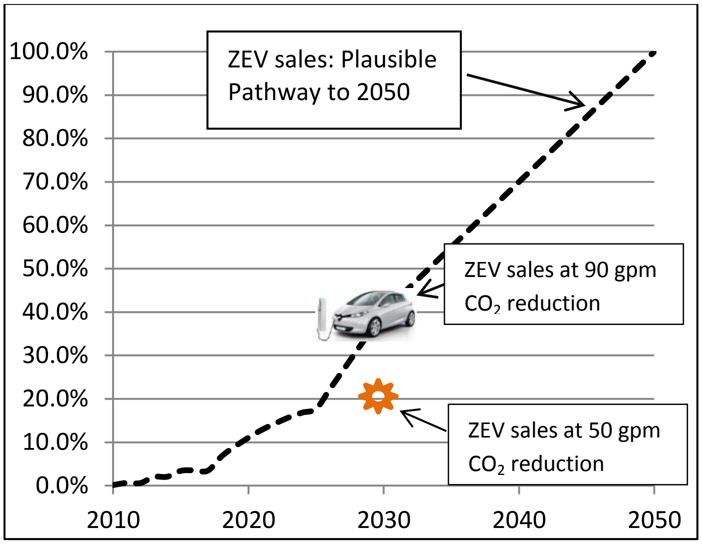
As shown in Table 6, the lifetime fuel savings far exceed the increased price of an average vehicle resulting from use of the technologies needed to reduce CO_2 emissions. The payback period, which is the point where the fuel savings are greater than the increased price of the new vehicle, is about 5 years. This is within the average 6.5 year period of ownership of a new vehicle.[30] For comparison, the payback period for the current 2025 standard is also 5 years.

There are a number of implications of these results. One important issue is what CO_2 reduction, and the associated increase in new ZEV sales, puts us on a pathway that would achieve the goal of an 80 percent CO_2 emissions reduction for the in-use fleet by 2050. Figure 7 below, produced by CARB, shows a possible pathway (dashed line) for California to meet the 2050 goal. The 40 percent ZEV sales in 2030 from our modeling at a 90 gpm CO_2 reduction, shown by the car image, is on the CARB trend line. The ZEV sales for a 50 gpm CO_2 reduction fall considerably short of the line.

[30] Statista, Average length of vehicle ownership in the United States in 2015, by vehicle type (in years), https://www.statista.com/statistics/581017/average-length-of-vehicle-ownership-in-the-united-states-by-vehicle-type/ (last visited February 23, 2017).

FIGURE 7

Annual Sales of ZEV Passenger Cars Consistent with Achieving a Fleet-wide On-Road 80 Percent CO_2 Reduction by 2050 in California



Another issue is the lead time to adopt technology. Many of the conventional technologies that could further reduce CO_2 emissions involve significant changes to a vehicle, such as adding a 48 volt system for mild hybrids, and new engines based on the Atkinson cycle. If the CO_2 standards required are set forth by 2020, there should be ample time to achieve widespread introduction of these technologies by 2030.

All the scenarios involve some weight reduction, which in general increases gradually as the CO_2 targets become more stringent. EPA and NHTSA have studied the subject of whether weight reduction will increase the number of fatalities. In general weight reduction in small vehicles increases fatalities, and the same weight reduction in larger vehicles decreases fatalities. A detailed discussion of the results can be found in Chapter 8 of the 2016 TAR. Over the lifetime of 2021 to 2025 model year vehicles studied in the TAR, a net savings of 74 lives was calculated. EPA included an algorithm in OMEGA to keep track of the impact of weight reduction selected by the model to reduce CO_2 emissions. For each of the scenarios included in this paper, the result is a net reduction in fatalities.

The challenge for ZEV technologies is a bit different. Widespread introduction of ZEV models is possible by 2030, and has already begun as evidenced by the rapidly increasing number of models expected to be available by 2020. Several announcements by OEMs suggest ZEVs could account for 15 to 25 percent of sales by 2025 (see Section IV). There should also be time to build battery manufacturing capacity and install needed charging infrastructure, both of which have already begun (e.g. the Tesla Gigafactory, announcements of new battery production plants in Europe, and announcements of plans to install fast chargers on many interstate highways). [31]

[31] Tom Randall, Tesla Flips the Switch on the Gigafactory, BLOOMBERG (January 4, 2017), *available at* https://www.bloomberg.com/news/articles/2017-01-04/tesla-flips-the-switch-on-the-gigafactory; Graham Prophet, Gigafactory Battery Factory in Europe Opens, EE Times (May 18, 2016), *available at*

A significant uncertainty is whether the consumer will want to buy ZEV technologies in the volume (40 percent of new passenger vehicle sales) that is necessary to reduce CO_2 emissions by 90 gpm in 2030. This would require a substantial increase in the sales volume of ZEVs year over year from 2025 to 2030.

Also, as discussed previously, the OMEGA model generally does not select PHEVs as long as BEVs are available because PHEVs do not reduce CO_2 emissions as much as BEVs, and their cost is comparable to or more than the cost of BEVs. The market suggests otherwise since PHEVs are being offered for sale (e.g. Chevy Volt and Chrysler Pacifica), and more models have been announced for introduction. Notwithstanding the model's least cost algorithm, we expect PHEVs will capture a significant share of ZEV sales at least through 2030.

Another limitation of modeling in which the outcomes are a decade or more away is innovation is not assumed. For example, in EPA's 2012 rulemaking the Atkinson cycle engine which was being introduced by Mazda was not considered to be widely used by 2025. In EPA's 2016 TAR, the Atkinson cycle engine is projected to be a commonly used technology by 2025. As has happened in the past, the innovation of the automobile industry will undoubtedly result in new and improved technologies introduced that will be used to further reduce CO_2 emissions.

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http://www.eetimes.com/document.asp?doc_id=1329703; EVgo, https://www.evgo.com/ (last visited February 23, 2017).

VI. Issues and Further Considerations

In this section we identify a few of the issues that undoubtedly will come up during consideration of a next set of CO_2 and ZEV regulations, and address these issues as they relate to achieving much greater CO_2 emission reductions and sustainable commercialization of ZEVs.

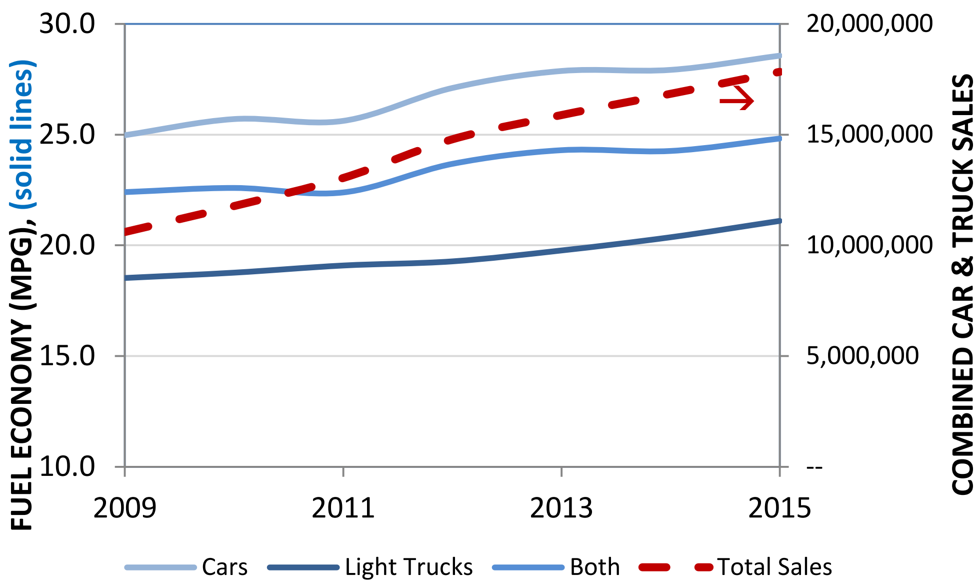
Health of the auto industry

Certain automakers have commented during the midterm evaluation that the 2022-2025 standards need to be weakened, claiming that they will not be able to meet the standards or that the technologies needed will be too costly. These comments seem at odds with the automakers' public support for the standards during the rulemaking process in 2011, the dramatic improvement in the economic health of the auto industry since that time, and the fact that automakers are ahead of schedule in meeting the current standards.

After near collapse during the economic recession, the auto industry has returned to profitability, selling more cars in 2015 than ever before.[32] This comes at the same time fleet-wide fuel economy has climbed to its highest level ever (see Figure 8 below).

FIGURE 8

Sales and Fuel Economy Have Steadily Risen Since 2009



Source: Created by EDF from data available from Wards Auto[33] and the EPA Fuel Economy Trends Report[34]

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[32] Sales rose again in 2016 to set a new record. *See, e.g.*, David Phillips, *U.S. industry hits new peak behind solid GM, Nissan, Honda gains*, AUTOMOTIVE NEWS (January 4, 2017), *available at* http://www.autonews.com/article/20170104/RETAIL01/170109972/gm-nissan-sales-strong-as-industry-flirts-with-record.

During its return to profitability the auto industry also added jobs. Since the recession, overall job growth in the industry has been strong, adding nearly 700,000 direct jobs and aiding a recovery of U.S. manufacturing as a whole.[35] In addition to the current robust economic health of the auto industry, analysis by Ceres shows that U.S. automakers and their parts suppliers will continue to make profits under the 2022-2025 standards and will be better positioned to avoid another downturn in the event of any fuel price shocks.[36]

Automakers are also ahead of schedule in meeting the current Phase 2 standards, exceeding the fuel economy and GHG standards in each of the last four years. And today there are over 100 car, SUV, and pickup versions on the market that already meet 2020 or later standards.[37] And the recent TAR and analyses supporting the Preliminary Determination both concluded that automakers will be able to meet current and future standards at lower costs than originally estimated. In addition, many automakers have stated in SEC filings that they are positioned to cost-effectively meet the current and future standards.[38]

All of these signals point to a healthy auto industry that is on track to meet the Phase 2 standards.

Structure of the current CO_2 ***emissions performance standards***

The current structure of CO_2 emissions performance standards through 2025 has effectively reduced CO_2 emissions (and fuel consumption) while providing flexibility to the vehicle manufacturers to innovate with new technologies, and accommodates the shifting preferences of the new car buying consumer. Similarly, the CARB ZEV mandate has stimulated a nascent market for ZEVs, and encouraged technology advancements such as the 238 mile range Chevy Bolt BEV and Toyota fuel cell Mirai. The flexibility provided by the credit trading provisions of the standards have helped individual vehicle manufacturers comply.

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[33] *See* Wards Auto, Data & Insights, http://www.WardsAuto.com/data-center (last visited February 23, 2017).

[34] *See* EPA, *Light-Duty Automotive Technology, Carbon Dioxide Emissions, and Fuel Economy Trends: 1975 Through 2016* (November 2016), *available at* https://www.epa.gov/fuel-economy/trends-report.

[35] BlueGreen *Alliance, Sound Vehicle Standards & Policies Drive Strong Job Growth, A summary of research and analysis of the impact of CAFE standards on job growth in the United States*, June 2016, https://www.bluegreenalliance.org/resources/sound-vehicle-standards-policies-drive-strong-job-growth/ (last visited February 23, 2017). *See also,* Nicholas Bianco, *5 Things You Should Know About America's Clean Car Standards* (December 2016), http://blogs.edf.org/climate411/2016/12/19/5-things-you-should-know-about-americas-clean-car-standards/ (last visited February 23, 2017).

[36] Ceres, *Economic Implications of the Current National Program v. a Weakened National Program in 2022-2025 for Detroit Three Automakers and Tier One Suppliers* (June 2016), https://www.ceres.org/files/analyst-brief-economic-effects-on-us-automakers-and-suppliers/at_download/file (last visited February 23, 2017).

[37] EPA, Midterm Evaluation for Light-Duty Greenhouse Gas Emissions Standards for Model Years 2022-25, https://www.epa.gov/regulations-emissions-vehicles-and-engines/midterm-evaluation-light-duty-vehicle-greenhouse-gas-ghg (last visited February 23, 2017).

[38] Environmental Defense Fund, *Automakers and Labor: Strong Support for America's Clean Car Standards*, http://blogs.edf.org/climate411/files/2016/11/Automakers-and-Labor-Strong-Support-for-Americas-Clean-Car-Standards.pdf?_ga=1.182973030.1996587957.1476292269 (last visited February 23, 2017).

For example the footprint-based CO_2 emission standards were designed to provide similar emission reduction stringency for all vehicle types, while recognizing that absolute emissions are inherently greater for larger vehicles than small. The flexibility in this provision helps assure that the standards will not force consumers to accept smaller vehicles they may not desire, or limit the availability of large pick-up trucks or SUVs. In fact, as of 2016 consumers have been purchasing more light trucks (especially crossovers) than had been anticipated at the time the standards were adopted in 2012, yet the new vehicle fleet is emitting below the current GHG standard. The fuel economy standard adjusts to reflect the trend of purchasing larger vehicles, with the standard for 2025 models decreasing from 54.5 mpg to 51.4 mpg. The regulation's flexible structure has assured consumers have a full selection of the vehicle types they desire, and this is expected to continue in the future. Fuel economy will still nearly double compared to 2010 despite the trend of buying larger, higher emitting vehicles.

Other flexibilities in the CO_2 standard such as averaging emissions across a manufacturer's fleet, banking and trading of credits, and a simplified procedure for obtaining credit for emission reductions achieved through new technologies such as aerodynamic devices and less damaging refrigerants have helped vehicle manufacturers achieve CO_2 emissions rates that are lower than the standards through the current model year, most likely at a lower cost. A wider selection of pathways to comply with the standards helps to further ensure standards are feasible and cost-effective. The 2016 TAR and EPA FD make a clear case that sufficient technologies exist to meet the 2025 CO_2 standard, at a reasonable cost. The expected underutilization of some of the currently available technologies in 2025 provides support that there is room for achieving additional reductions in 2026 and beyond.

Overall, there is no strong argument that the current standards through 2025 need to be revised or restructured. Compliance is occurring today, and the TAR and FD factually demonstrate that compliance through 2025 is feasible at equal or lower cost than had been forecast in 2012. EPA's Final Determination in January 2017, confirms the current standards should not be revised.[39]

Structure of post-2025 CO_2 *emissions performance standards*

Compliance with the current CO_2 standard through 2025 can be accomplished largely by improving the efficiency of the gasoline fueled vehicle drive train and changes to the vehicle structure to lower weight and reduce aerodynamic drag, as demonstrated in the TAR and FD. The TAR and FD also indicate only a few percent of alternative technology vehicles, namely plug-in electric vehicles, will need to be used by vehicle manufacturers as a method of compliance through 2025.

As discussed in Section V of this report, more stringent CO_2 emission standards for 2026 and beyond would result in greater use of zero or near-zero emission vehicles. In addition, it is likely that passenger mobility will significantly change as self-driving cars, and increased use of ride hailing and ride sharing enter the marketplace. These trends need to be considered when

[39] Some OEMs are arguing that the EPA and NHTSA regulations are not entirely consistent, but resolving these issues is independent from and need not require revisiting the stringency or timing of current regulations.

developing a next set of CO_2 standards, from the standpoints of accommodating these technologies if they contribute to lower CO_2 emissions, and if necessary incentivizing them. Some of the implications for the structure of a future standard are discussed next.

More zero emission vehicles

The CARB ZEV program would need to remain in place and be significantly strengthened beyond 2025 to support the rapid increase in ZEV sales that would be necessary to continue reductions in CO_2 emissions beyond 2025. The current program is based on a system of credits, which is designed to preferentially encourage marketing of environmentally superior technologies such as longer range BEVs, and promising technologies such as fuel cell vehicles, whose development currently lags plug-in electric vehicles. As the market grows for these technologies, alternative forms of the credits more closely related to each technology's environmental performance have been suggested. Through UC Davis, CARB is currently collecting data from in-use BEVs and PHEVs in typical multi-vehicle households to determine the actual annual miles traveled using electricity. Data collection will continue in 2017. These data can be used to factually evaluate the need for revisions to the credit system that would be supportive of growth in the types and number of ZEVs entering the market.

In considering changes to the ZEV credit system, it is important to continue to assure that the resulting credit program encourages development of vehicles that can meet customer driving needs with zero emissions, to the greatest extent possible. This suggests the credit system should not excessively incentivize technologies such as low range PHEVs that still depend significantly on gasoline to fulfill driving needs. Data from in-use generation 1 Chevy Volts (38 mile electric range) indicate 60 to 70 percent of the annual miles are on electricity, whereas a Ford Fusion 20 mile PHEV uses electricity for only about 30 percent of its miles traveled.[40] Should a revised credit system preferentially incentivize lower range PHEVs causing them to dominate the market instead of vehicles such as long range BEVs or FCEVs capable of 15,000 miles of zero emission operation annually, achieving the long range climate goals discussed in Section II would not be possible for the passenger vehicle sector. Thus achieving longer term goals should be kept in mind in developing post-2025 standards, especially as it relates to ZEVs.

One national program

The auto manufacturers have long advocated for one emission reduction program to apply to the entire country. To help vehicle manufacturers achieve their goal, CARB currently accepts compliance with the EPA CO_2 emission regulation for passenger cars as compliance with California CO_2 requirements, resulting in a One National Program (ONP) for CO2 emission standards. However, vehicle manufacturers must in addition comply with the CARB ZEV program because there is no comparable EPA program which requires sale of ZEVs on a national level.

[40]Ryan Hart, Analysis of Plug-In Electric Vehicle Usage (September, 2016), https://www.arb.ca.gov/msprog/consumer_info/advanced_clean_cars/oem_pev_driving_and_charging_characteristics_ryan_hart.pdf (last visited February 23, 2017).

Vehicle manufacturers continue to advocate for harmonization of all federal and California vehicle emission control programs, including the CARB ZEV program, as critical to achieving their goal of ONP.[41] One way to achieve the ONP is to modify the EPA CO_2 regulation to include a national ZEV requirement. Another way is to eliminate California's unique ZEV requirement. However elimination of the California ZEV requirement seems unlikely at this time and problematic for several reasons. Governor Brown and the California Legislature have made a strong commitment to substantially reducing GHG emissions from all sources, and one of the largest sources of GHGs is motor vehicles. The state has made and continues to make large investments in refueling and charging infrastructure for ZEVs, and provides purchase incentives to support a growing market for ZEVs. The nine other states that have adopted the California ZEV program are also investing in preparation for a growing market for ZEVs in their states.

While the current EPA CO_2 program does not include a ZEV requirement, it is not blind to the CARB ZEV program, as some have suggested. For example, the EPA regulation provides CO_2 credits for each ZEV sold anywhere in the USA, and through 2021 doubles the credits. Each ZEV sold is counted as zero CO_2 emissions and provides a much large CO2 emission reduction than any conventional ICE vehicle. As a result, the CO_2 reduction required by the remainder of combustion-engine vehicles a manufacturer sells is reduced.[42] Thus the current EPA standard provides an additional CO_2 emission reduction benefit to OEMs that sell ZEVs, including from the ZEVs used to meet California ZEV requirements.

Can post-2025 standards be structured to more closely achieve the OEM's goal of ONP, especially if both the CO_2 standards and the CARB ZEV regulation become more protective, as this paper suggests is feasible? One obvious way would be for EPA and CARB to work closely together with the shared objective of adopting more protective standards and requirements that balance feasible CO_2 emission reductions and costs, and that achieve a cost effective transition to a sustainable market for zero and near-zero vehicles necessary to meet science-based emission reduction goals and international climate agreements. This could be most directly achieved if a national ZEV requirement were adopted.

Even in the absence of a national ZEV requirement, it should be possible to structure a national CO_2 regulation that uses credits and/or other incentives that recognize the transition to a sustainable market for ZEVs may occur at different rates in different parts of the country, and be influenced by the emergence of new mobility approaches that could involve ZEV vehicles.

California and the Section 177 states that adopted CARB's ZEV regulation have worked together with OEMs to provide credits and other mechanisms that recognize that development of markets for ZEVs in some areas may differ from California due to different incentives, consumer preferences and the rate of installing charging infrastructure. A similar cooperative process

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[41] Alliance of Automobile Manufacturers and the Association of Global automakers, Light-Duty Vehicle CAFÉ and CO_2 Standards: Key Considerations for the Mid-Term Review, June 2016

[42]For example, consider an OEM that must reduce CO_2 emissions of vehicles sold in a given year from an average of 250 g/mi. to 200 g/mi. in order to meet the EPA CO_2 standard. The manufacturer could reduce CO_2 emissions from each vehicle sold by 50 g and comply with the 200 g standard. The OEM could also meet the EPA standard by selling one BEV for every 5 vehicles sold (the BEV counts as zero emissions, in this example providing a reduction of 250 g, the same as reducing 5 vehicles emission by 50 g each.), or by any combination of these two approaches.

could result in flexibilities compatible with the structure of a national CO_2 emission standard that achieve the ONP goal.

Upstream emissions

EPA's CO_2 regulation for 2017-2025 assigns zero gram/mile CO_2 emissions to PHEVs, EVs and FCEVs until the 2025 model year.[43] EPA argued excluding upstream emissions from compliance values provides a needed incentive for these emerging and potentially game-changing technologies. However, in the absence of federal policies to reduce emissions from upstream sources, EPA also adopted a sunset that ends this incentive no later than 2025, or earlier if a manufacturer's ZEV production during 2022-25 exceeds a specified cap. Subsequent compliance values for ZEVs will include upstream CO_2 emissions.

The vehicle manufacturers have argued they cannot be responsible for reducing upstream emissions from electrical generation any more than they can be responsible for reducing the carbon footprint of gasoline. EPA estimated as part of the FD that the nationwide average CO_2 emissions from generating electricity to charge a compact battery electric vehicle is about 80 grams per mile in 2025.[44] The power sector and the passenger vehicle sector are two of the largest sources of greenhouse gas emissions. It is important to design future standards that create incentives for reducing emissions from both sectors and that encourage advanced zero emitting technologies.

Since the current vehicle CO_2 standards were finalized, there have been federal and state actions to reduce carbon emissions of new and existing power plants, and carbon-intensive electricity generation has been declining. In light of these trends and considering current U.S. and subnational policies, policymakers should assess how best to account for upstream emissions after model year 2025 and evaluate policies that simultaneously promote the reduction of upstream emissions and the development of these transformative technologies.

Refueling infrastructure:

Refueling facilities need to expand as the market uptake of ZEVs increases, and this will likely be influenced in part by future GHG and ZEV regulations. Establishing home electric recharging for those with single family homes with garages is well established and straightforward. To support an expanding market for ZEVs, local efforts to facilitate refueling installations at multi-unit residences and at workplaces will be needed.

Assuming market success of 200+ mile battery electric vehicles, fast charging that is designed to allow longer destination trips would be needed so more BEVs can serve as the primary vehicle for households. If shorter range BEV100s remain popular, more fast chargers within the urban core will provide a safety net for unplanned trips. In some states utilities are installing chargers,

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[43] Depending on a manufacturer's sales volume of ZEVs, accounting for upstream emissions could be required a few years before 2025.
[44] OMEGA Market File for 2025 Control Case for an average BEV200 vehicle.

and the recent settlement with VW will provide $2 billion over a decade to expand the refueling network nationwide and promote ZEVs.[45]

Development of hydrogen refueling stations will also be necessary if fuel cell vehicles are commercially successful. The challenge with hydrogen refueling is a network of urban stations must be established before vehicles are sold, since there is no home refueling option available as there is for plug-in vehicles. California's experience in initiating a hydrogen refueling network may provide valuable learnings helpful to expanding the network nationally.

If the market for ZEVs increases as OEMs are beginning to suggest it will (see Section IV), the installation of electric and hydrogen refueling stations nationwide will need to become more coordinated than it is today. This can be accomplished by involving refueling infrastructure sponsors and suppliers in a post-2025 CO_2 emission standard development process to help insure a refueling network that complements the types of ZEVs expected is established. If the marketplace, utilities and local government efforts are not adequate to respond to the vehicle market, policymakers should evaluate what incentives could be included in a 2026 and beyond CO_2 regulation to increase refueling capacity, including possible incentives for vehicle manufacturers, utilities or others to invest in refueling facilities.

Advances in mobility:

How we travel to accomplish our daily activities is beginning to rapidly change. New services such as Uber and Lyft are providing convenient options to personal car use, and opening up travel methods for those who do not have a personal vehicle or cannot drive. The emergence of autonomous vehicles also opens the possibility of more efficient transport, which could reduce the cost of a trip. Fewer accidents seem highly likely with autonomous vehicles.

How autonomous vehicles affect the amount of travel and CO_2 emissions has been investigated, but whether vehicle miles travelled (VMT) and CO_2 emissions increase or decrease remains unclear. For example autonomous driving could reduce CO_2 emissions through smoother driving and efficient routing, and higher occupancy through ride sharing. However increases in VMT and CO_2 emissions may also result from more travel by the non-driving population, increased average speed due to less congestion, and an overall increase in trips due to convenience and lower cost (rebound effect). One presentation at the 2013 Transportation Research Board's 2nd Annual Workshop on Road Vehicle Automation provided some quantification of possible energy demand of mobility changes, which illustrates the large range of possible outcomes.[46] Fuel demand ranged from a 5% reduction to a 10% increase in a scenario where 10 percent of privately owned cars had autonomous capability. In a shared ownership scenario with 90 percent autonomous cars, fuel demand varied from an increase of over 200% to a decrease of 87%. Much of the reduced fuel demand would come from using ZEV autonomous vehicles to reduce the CO_2 emission impact of increased VMT.

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45 EPA, Volkswagen Clean Air Act Civil Settlement, https://www.epa.gov/enforcement/volkswagen-clean-air-act-civil-settlement#civil (last visited February 23, 2017).
46 Austin Brown, *Autonomous Vehicles Have a Wide Range of Possible Energy Impacts* (July 16, 2013), http://www.nrel.gov/docs/fy13osti/59210.pdf (last visited February 23, 2017).

In developing 2026 and beyond CO_2 and ZEV standards, the future impacts of mobility changes on the environment must be considered. Future CO_2 standards offer an opportunity to help ensure the emerging autonomous technology and mobility services are environmentally sustainable, in a manner that maximizes the ability to reduce CO_2 emissions and helps advance the market for ZEVs. The challenge will be that autonomous vehicles and mobility changes will likely just be emerging around 2020, about the same time that CO_2 and ZEV standards for 2026 and beyond could be finalized and adopted.[47] Incentivizing vehicle manufacturers to produce and sell zero emission vehicles for use in mobility services can expand the market for ZEVs and reduce CO_2 emissions even in those applications that increase VMT.

Power and transportation nexus incentivizing decarbonization

As the prevalence of electric vehicles expands, the intersections between the transportation and electricity sectors are becoming more significant. More electric vehicles on the road mean more electricity demand for transportation. Future projections point to the potentially enormous scale—a recent analysis by Bloomberg New Energy Finance estimated that electric vehicles will add 2,700 TWh, or 8%, to global electricity demand in 2040. Already, investment in electric vehicle support infrastructure is increasing, including by electric utilities themselves. Through 2015, utilities had proposed to invest more than $1 billion to build more than 60,000 public electric vehicle chargers.[48]

Expanded deployment of electric vehicles offers a powerful opportunity to achieve deep decarbonization by leveraging the on-going transformation of the power sector. Since 2005, carbon dioxide emissions from the power sector have declined by 21 percent thanks to the declining cost of low and zero emitting electricity, consumer demand, and public policy. These trends are expected to continue in the years ahead.

As power sector emission levels decline, the possibility exists that there could be declining and diminishing greenhouse gas emissions associated with the operation of electric vehicles. The extent to which this is the case will depend on the specifics of power sector decarbonization policies adopted at the national and state levels and investments in clean energy by power companies. The balance of these factors should be considered in the development and implementation of current and future vehicle standards, in order to ensure that the program provides maximum investment certainty while reinforcing (and not undermining) the greenhouse gas reduction goals of the programs.

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[47] Ford, Ford *announces intention to deliver high-volume, fully* autonomous *vehicle for ride sharing in 2021* (Aug 16, 2016), https://media.ford.com/content/fordmedia/fna/us/en/news/2016/08/16/ford-targets-fully-autonomous-vehicle-for-ride-sharing-in-2021.html (last visited February 23, 2017).
[48] Business Council for Sustainable Energy, *2017 Sustainable Energy in America Factbook, http://www.bcse.org/sustainableenergyfactbook/* (last visited February 23, 2017).

Appendix

Methodology and Results

Introduction

In this appendix we describe in more detail 1) how we utilized EPA's OMEGA model to evaluate possible CO_2 emission reductions from passenger vehicles in the 2030 timeframe, and the impact on vehicle price; and 2) a methodology for projecting the cost of electrified vehicles to 2030.

We utilize the latest version of EPA's OMEGA model[49] to determine how available conventional technologies and emerging zero emission technologies (ZEVs) can be used to achieve various levels of CO_2 emission reduction in 2030, on an OEM-specific and fleet average basis. We modified the OMEGA model only where necessary to extend its output to 2030; incorporate the most recent estimates of the 2030 manufacturing cost of various ZEVs and compare those to EPA's estimates of ZEV costs; and create several scenarios that help us understand the relative role conventional technologies and ZEVs may play in achieving lower CO_2 emissions from the passenger vehicle fleet.

Specifically we revised the OMEGA model's caps (limits) on use of recently developed technologies, including ZEVs, as appropriate for 2030; extended the learning curves in the model to 2030, included sales estimates for 2030, and excluded upstream CO_2 emissions which EPA began to include with the 2025 model year. The updated manufacturing costs for ZEVs we used in some scenarios were based on a study provided by the ICCT that was published in the summer of 2016. The ICCT study provided cost estimates for a small passenger car. We describe how we extended these estimates to other classes of vehicles, and adjusted the results to be compatible with the OMEGA modeling procedure. All references to EPA procedures and computer files are to those described or distributed as part of the PD.

We also provide more detailed model outputs for all seven scenarios we evaluated, including the three we discuss in the body of the report.

Recent Electrified Vehicle Cost Estimates by ICCT

Paul Wolfram and Nic Lutsey recently conducted a review of cost projections for electrified vehicles: plug-in hybrids (PHEV), battery electric vehicles (EV) and fuel cell vehicles. The review covered the 2015-2030 timeframe and was published by the International Council for Clean Transportation (ICCT). Using cost projections from a variety of sources, they made their own projections of the cost of various electrified vehicles relative to a conventional gasoline-fueled vehicle, using the latest information available. They focused their analysis on the costs of these technologies for a low, medium car. A summary of their analysis is shown in Table 1 (costs

[49] Nov. 2016 version of OMEGA that was used to evaluate the adequacy of the current 2022-2025 CO2 emission standards as part of the EPA Proposed and Final Determination process

presented in Euros were converted to US$ by dividing by 0.79 (the same conversion factor used in the ICCT report).

Wolfram and Lutsey evaluated ten types of electrified vehicles, including battery electric vehicles (EVs), plug-in hybrid vehicles (PHEVs), and a fuel-cell vehicle. Eight EVs and PHEVs are shown below. The numbers following the vehicle type designator indicates the range of the vehicle on all-electric operation in miles. The costs are those incremental to a 2010 vehicle. Wolfram and Lutsey do not describe the specific engine and transmission technology assumed to be present on this vehicle. We assume here that the engine and transmission present on this (presumably European) 2010 vehicle is fairly basic and in broad terms compatible to the base vehicle used by EPA in its costing methodology. To the extent that there are differences, the base drivetrain assumed by EPA in it costing methodology is likely to be simpler than that assumed by Wolfram and Lutsey. In general, EPA assumes that the engine has no valve timing or lift variability and the transmission is a 4-speed automatic. While there were many drivetrains of this type in use in 2010 in Europe, many engines included additional technologies and there were numerous 5 and 6 speed transmission in production. Directionally, this would reduce the incremental electrified vehicle costs estimated by Wolfram and Lutsey relative to those developed by EPA.

The costs presented by Wolfram and Lutsey were presented in Euros, using a conversion factor of 1 dollar to 0.79 Euro, when applicable. We have converted these costs to U.S. dollars using the same conversion factor. Finally, Wolfram and Lutsey made their projections for a low medium European car. We assume here that this is equivalent to the smallest curb weight vehicle used by EPA in its costing of technology, curb weight category 1.

TABLE A1

Incremental Costs of Electrification of a Low Medium Car Relative to a 2010 Car

ICCT Vehicle Type and ICCT Range in Miles	2015	2020	2025	2030
EV-100	$7,152	$3,796	$1,736	$466
EV-150	$10,949	$6,325	$3,462	$1,758
EV-200	$14,747	$8,786	$5,062	$2,865
EV-300	$22,342	$13,707	$8,261	$5,080
PHEV-20	$4,927	$3,860	$3,124	$2,297
PHEV-30	$6,096	$4,689	$3,669	$2,696
PHEV-40	$7,224	$5,489	$4,195	$3,109
PHEV-60	$9,354	$6,999	$5,189	$3,508

As can be seen, the costs for all eight technologies are projected to decrease dramatically through 2030. The projected cost of EVs decreases more dramatically than those for PHEVs, despite the fact that both types of vehicles use similar types of batteries and electrical components. The difference in the degree of cost reduction is due to the fact that the costs for EVs include a reduction in cost for the removal of the conventional gasoline engine and transmission. This credit is unaffected by the reduction in the cost of electrical components and battery technology. As the cost of electrification approaches the cost of the conventional drivetrain, the net cost of EVs can become quite small. Since PHEVs continue to utilize a conventional drivetrain, their costs decrease at a slower rate.

Based on communication with Lutsey, their estimate of all-electric range was based on a European test cycle. Lutsey estimated that their range for EVs should be discounted by 16% to be comparable to the range nomenclature used by EPA in their draft Technical Assessment Report. The EPA range is based on the window label estimate, which better represents the range achievable in actual driving. Similarly, the ICCT range for PHEVs should be discounted by 37%. Per Lutsey, adjusting for a change in vehicle range would only affect the size and cost of the battery. For EVs and PHEVs, respectively, battery costs changed linear with vehicle range, so we applied this relationship when adjusting the ICCT battery costs to match the vehicle ranges addressed by EPA in its analysis: for EVs: 75, 100 and 200 miles; for PHEVs: 20 and 40 miles.

As Wolfram and Lutsey did not mention applying any vehicle weight reduction in their analysis, we assumed that none was applied. When comparing the ICCT EV/PHEV costs to those of EPA, we selected the EPA cost estimates for their zero weight reduction case.

EPA included five types of electrified vehicles in its PD analysis: EV75, EV100, EV200, PHEV20, and PHEV40. The vehicles evaluated by ICCT which come closest to these five EPA vehicle designs are the EV100, EV150, EV300, PHEV30 and PHEV60. This matching was done to minimize the degree of battery cost adjustment associated with a change in all electric vehicle range. We obtained a breakdown of EV and PHEV costs into non-battery components, battery, and credit for removal of the internal combustion engine (ICE) and transmission (EVs only) from ICCT. We then adjusted the battery cost so that the vehicle's all-electric range would match that assumed by EPA. Again, battery costs were assumed to be proportional to all-electric vehicle range, which was consistent with the original ICCT cost projections. The results are shown in Table A2 below.

TABLE A2

ICCT Incremental Costs Compared to a 2010 Conventional Vehicle (Converted to EPA-Equivalent Range), Low Medium (Small) Car

EPA Vehicle Type and EPA Range	2015	2020	2025	2030
EV-75	$6,338	$3,269	$1,393	$229
EV-100	$8,599	$4,802	$2,472	$1,073
EV-200	$17,640	$10,661	$6,280	$3,709
PHEV-20	$6,296	$4,830	$3,762	$3,180
PHEV-40	$9,743	$7,275	$5,370	$4,398

These projected costs are compared below to EPA's projected costs for these vehicle types used in their final rulemaking and the recent PD.

EV and PHEV Costs in EPA's PD Analysis

EPA conducted its own analysis of a wide range of projections of electrification costs in both the TAR and the PD. These projections addressed six vehicle classes, though the definition of the six classes changed between the TAR and the PD. In the TAR, EPA developed costs for six classes of vehicles: small cars, standard cars, large cars, small multiple purpose vehicles (MPVs), large MPVs and trucks. In the PD, EPA changed its classification system for cost purposes to one based on curb weight, with class 1 having the lowest curb weight and 6 having the highest curb weight. In the computer files which were distributed as part of the PD package, the file containing the most detailed breakdown of EV costs, BatteryCostingCalculator_PD2016_20161012_2015$.xlsx, continued to use the nomenclature used in the TAR. However, all of the subsequent files use the new nomenclature, which we also use here. The assignment of these costs to the 29 vehicle types is handled directly by EPA's OMEGA pre-processing programs. As we used these same pre-processing programs here, this assignment was conducted in the same way as that done by EPA for the PD.

EPA first developed estimates of direct manufacturing costs for each type of electrified vehicle technology and then added indirect cost multipliers to produce total cost estimates at the consumer level. As mentioned above, the electrified vehicle costs developed by Wolfram and Lutsey apply to a low medium car. We conservatively assumed that this vehicle is equivalent to EPA's smallest vehicle class, which averages 2822 pounds (lbs). It is possible that a low medium car could be closer to EPA's curb weight class 2, which averages 3285 lbs. If so, then the ICCT-based costs estimated below would be several hundred dollars too high. Also, given the sources used by Wolfram and Lutsey, which included several also used by EPA, and the absence of any discussion of indirect cost multipliers or retail price equivalent costs, the ICCT cost projections appear to represent direct manufacturing costs. Table A3 shows EPA's cost projections for the five electrified vehicle types discussed in the PD. (These costs were taken from EPA's OMEGA_TechCosts_8405.xlsx spreadsheet.)

TABLE A3

EPA Electrified Vehicle Direct Manufacturing Costs – Small Car –Compared to a 2010 Conventional Vehicle

	2015	2020	2025	2030
EV-75	$7,084	$5,062	$4,156	$3,680
EV-100	$7,984	$5,708	$4,689	$4,153
EV-200	$11,086	$7,937	$6,526	$5,782
PHEV-20	$6,685	$5,222	$4,525	$4,132
PHEV-40	$8,607	$6,954	$5,934	$5,361

These estimates at the direct manufacturing cost (DMC) level were produced by 1) setting the inputs to EPA's OMEGA_TechCost_Inputs.xlsx spreadsheet to request cost estimates for 2015-2030 and then 2) running EPA's python script, (OMEGA_TechCosts.py) to produce a version of EPA's OMEGA_TechCosts.xlsx spreadsheet. The DMC's for the battery and non-battery components for above EV and PHEV vehicles were taken from the EV techs worksheet.

As can be seen, the ICCT and EPA cost estimates are closest for model years 2015-2020, but diverge thereafter, with the ICCT cost projections decreasing more dramatically than those of EPA. Also, the two sets of cost projections are closer for PHEVs and more divergent for EVs. As indicated in the Introduction, the potential impact of these lower costs for PHEVs and EVs on future CO_2 emission reductions is one of the interests of this analysis. In order to maximize the comparability of the projections developed here with similar projections presented by EPA in the PD, we use EPA's OMEGA model for these projections. This requires that we develop ICCT-like costs for all six vehicle types, as well as include indirect cost multipliers in the electrification cost projections.

Extrapolation of ICCT Cost Estimates to Other Vehicle Types

The first step in extrapolating the ICCT cost projections for small cars to other vehicle classes was to examine how EPA's cost projections varied across the six vehicle classes. Table A4 shows the EPA's cost projections for a EV100, broken down into three categories: non-battery electrification components, credit for the removal of the conventional drivetrain and battery cost. This breakdown was chosen, as ICCT's cost projections for a small car could also be presented at this level. A further breakdown was not possible given differences in the breakdown of non-battery components in the ICCT and EPA analyses.

These costs are those at the direct manufacturing level and are again taken from EPA's spreadsheet: BatteryCostingCalculator_PD2016_20161012_2015$.xlsx. As described above, the non-battery electrification components and the credit for the removal of the conventional drivetrain represent those for the 2017 model year. Battery costs are for model year 2025. This difference is not important at this step, since the costs for the two different model years are not combined into a single estimate until later when they are placed on a consistent model year basis.

TABLE A4

EPA Direct Manufacturing Costs – EV75*

Curb Weight Class	1	2	3	4	5	6
Non-Battery Components	$2,557	$2,986	$3,160	$3,587	$4,162	$4,251
ICE credit	$(2,706)	$(2,706)	$(3,651)	$(3,573)	$(3,573)	$(4,913)
Battery	$3,819	$3,989	$4,099	$4,332	$4,912	$4,997
Ratio of Cost to Curb Weight Category 1						
Non-Battery Components	----	1.17	1.24	1.40	1.63	1.66
ICE credit	----	1.00	1.35	1.32	1.32	1.82
Battery	----	1.04	1.07	1.13	1.29	1.31
* Non-Battery Components and ICE Credit apply in 2017, battery cost for 2025						

As shown in Table A4, all three components of costs increase as one moves from a small car to the other vehicle classes. These costs increase to different degrees, however. The lower half of

Table A4 shows the ratio of each cost component to that for a curb weight category 1 vehicle (hereafter referred to as a small car). As can be seen, the three component costs change to a different degree for each vehicle class. Tables A5 through A8 show analogous information for EV100s, EV200s, PHEV-20s and PHEV-40s.

TABLE A5

EPA Direct Manufacturing Costs – EV100 *

Curb Weight Class	1	2	3	4	5	6
Non-Battery Components	$2,557	$2,986	$3,160	$3,587	$4,162	$4,251
ICE credit	$(2,706)	$(2,706)	$(3,651)	$(3,573)	$(3,573)	$(4,913)
Battery	$4,296	$4,547	$4,693	$5,079	$5,998	$6,009
Ratio of Cost to Curb Weight Category 1						
Non-Battery Components	----	1.17	1.24	1.40	1.63	1.66
ICE credit	----	1.00	1.35	1.32	1.32	1.82
Battery	----	1.06	1.09	1.18	1.40	1.40
* Non-Battery Components and ICE Credit apply in 2017, battery cost for 2025						

TABLE A6

EPA Direct Manufacturing Costs – EV200 *

Curb Weight Class	1	2	3	4	5	6
Non-Battery Components	$2,559	$2,987	$3,161	$3,587	$4,162	$4,254
ICE credit	$(2,706)	$(2,706)	$(3,651)	$(3,573)	$(3,573)	$(4,913)
Battery	$5,932	$6,255	$6,460	$6,846	$7,828	$7,841
Ratio of Cost to Curb Weight Category 1						
Non-Battery Components	----	1.17	1.24	1.40	1.63	1.66
ICE credit	----	1.00	1.35	1.32	1.32	1.82
Battery	----	1.05	1.09	1.15	1.32	1.32
* Non-Battery Components and ICE Credit apply in 2017, battery cost for 2025						

TABLE A7

EPA Direct Manufacturing Costs – REEV20 (PHEV20)

	Small Car	Standard Car	Large Car	Small MPV	Large MPV	Truck
Non-Battery Components	$2,183	$2,404	$2,486	$2,653	$2,968	$2,990
Battery	$2,448	$2,589	$2,643	$2,791	$3,025	$3,017
Ratio of Cost to Curb Weight Category 1						
Non-Battery Components		1.10	1.14	1.22	1.36	1.37
Battery		1.06	1.08	1.14	1.24	1.23

TABLE A8

EPA Direct Manufacturing Costs – REEV40 (PHEV40)

Curb Weight Class	1	2	3	4	5	6
Non-Battery Components	$2,667	$3,045	$3,195	$3,592	$4,061	$4,149
Battery	$3,223	$3,468	$3,614	$3,935	$4,837	$4,936
Ratio of Cost to Curb Weight Category 1						
Non-Battery Components		1.14	1.20	1.35	1.52	1.56
Battery		1.08	1.12	1.22	1.50	1.53

ICCT Costs for All Vehicle Classes

The cost ratios presented in Tables A4 through A8 above are used to produce projected costs for the five vehicle classes not addressed directly by the ICCT analysis. The first column of costs in Table A9 below presents the breakdown of ICCT cost projections for a small EV75 car in 2030. The last five columns present analogous cost projections for the other five vehicle classes using the cost ratios from Table A4. For example, the ICCT cost of $2251 for non-battery components for a small car is multiplied by a factor of 1.17 from Table 4 to produce a cost of $2847 for the non-battery components for a standard car.

TABLE A9

ICCT Costs in Dollars in 2030 – EV75

Curb Weight Class	1	2	3	4	5	6
Non-Battery Components	$2,251	$2,847	$4,435	$2,666	$3,556	$3,960
ICE credit	$(4,000)	$(4,000)	$(5,398)	$(5,282)	$(5,282)	$(7,263)
Battery	$1,977	$2,201	$2,898	$2,253	$2,685	$2,923
Total	$229	$1,049	$1,935	$(363)	$959	$(380)

The same methodology was used to generate the cost projections for EV200, PHEV20 and PHEV40 vehicles in the five vehicle classes not directly assessed by ICCT. These figures are shown in Tables A10 through A13.

TABLE A10

ICCT Costs in Dollars in 2030 – EV100

Curb Weight Class	1	2	3	4	5	6
Non-Battery Components	$2,436	$2,845	$3,010	$3,417	$3,965	$4,050
ICE credit	$(4,000)	$(4,000)	$(5,398)	$(5,282)	$(5,282)	$(7,263)
Battery	$2,637	$2,790	$2,880	$3,117	$3,681	$3,688
Total	$1,073	$1,635	$492	$1,252	$2,364	$475

TABLE A11

ICCT Costs in Dollars in 2030 – EV200

Curb Weight Class	1	2	3	4	5	6
Non-Battery Components	$2,436	$2,844	$3,010	$3,416	$3,962	$4,050
ICE credit	$(4,000)	$(4,000)	$(5,398)	$(5,282)	$(5,282)	$(7,263)
Battery	$5,273	$5,560	$5,742	$6,085	$6,958	$6,970
Total	$3,709	$4,404	$3,354	$4,219	$5,639	$3,757

TABLE A12

ICCT Costs in Dollars in 2030 - REEV20

Curb Weight Class	1	2	3	4	5	6
Non-Battery Components	$1,898	$2,091	$2,162	$2,308	$2,582	$2,600
Battery	$1,281	$1,355	$1,383	$1,460	$1,583	$1,579
Total	$3,180	$3,445	$3,545	$3,768	$4,165	$4,179

TABLE A13

ICCT Costs in Dollars in 2030 – REEV40

Curb Weight Class	1	2	3	4	5	6
Non-Battery Components	$1,898	$2,167	$2,274	$2,557	$2,891	$2,953
Battery	$2,500	$1,379	$1,437	$1,564	$1,923	$1,962
Total	$4,398	$3,546	$3,711	$4,121	$4,814	$4,915

These "ICCT" cost projections are used along with EPA cost projections for 2030 to project two sets of fleet cost estimates for various CO_2 emission reductions in 2030 below.

Effect of Weight Reduction on EV/PHEV Costs

In its PD, EPA estimates the impact of weight reduction on the cost of EV and PHEV technology. The lower the weight of the vehicle, the lower the cost of both the battery and non-battery components of these technologies. Table A14 shows the base cost of the battery and non-battery components (without the ICE drivetrain credit) for an EV75 for the six vehicle types, as well as the reduction in this cost for a 100% reduction in vehicle weight. (These figures were taken from the TechCosts_Inputs spreadsheet included in the EPA public distribution of OMEGA related files used in its PD analysis.) The effect of realistic reductions in vehicle weight are determined as a simple fraction of the percentage weight reduction. Negative cost figures represent a reduction in cost with weight reduction. Positive cost figures represent an increase in cost with weight reduction.

The battery costs represent those for the year 2030, while the non-battery costs represent those for the year 2017. This difference is not an issue, as the relationship of these costs (e.g., their percentage differences) stays the same across time. Thus, these percentages can be applied to any model year, including 2030 as done below.

TABLE A14

EPA Electrification Cost Reduction per Weight Reduction: EV75

Curb Weight Class	1	2	3	4	5	6
Battery						
Base Cost	$3,820	$3,987	$4,096	$4,327	$4,888	$5,000
Change in cost with a 100% Wt. Reduction	$(761)	$(1,136)	$(1,313)	$(984)	$(1,942)	$(2,036)
	-20%	-29%	-32%	-23%	-40%	-41%
Non-Battery with no ICE credit						
Base Cost	$3,851	$4,280	$4,906	$5,295	$5,871	$4,382
Change in cost with a 100% Wt. Reduction	$110	$148	$165	$214	$260	$275
	3%	3%	3%	4%	4%	4%

The same methodology was applied to EPA's cost estimates for EV100, EV200, PHEV20 and PHEV40 vehicles. The results are shown in Tables A15-18 below. The effect of weight reduction on some PHEV40 battery and non-battery component costs seem to be more erratic than is the case for the other EV types, particularly for curb weight classes 4, 5, and 6. The reason for this is not known. In order to be as consistent as possible in our comparative OMEGA runs, we have left these figures as is, as they affect the EPA cost and ICCT cost OMEGA runs consistently.

TABLE A15

EPA Electrification Cost Reduction per Weight Reduction: EV100

Curb Weight Class	1	2	3	4	5	6
Battery						
Base Cost	$4,295	$4,523	$4,691	$5,041	$6,012	$6,023
Change in Cost for 100% Wt. Red.	$(1,098)	$(1,564)	$(1,951)	$(2,925)	$(5,715)	$(5,261)
	-26%	-35%	-42%	-58%	-95%	-87%
Non-Battery with no ICE credit						
Base Cost	$3,851	$4,280	$4,906	$5,295	$5,871	$6,601
Change in Cost for 100% Wt. Red.	$110	$147	$164	$212	$257	$273
	3%	3%	3%	4%	4%	4%

TABLE A16

EPA Electrification Cost Reduction per Weight Reduction: EV200

Curb Weight Class	1	2	3	4	5	6
Battery						
Base Cost	$5,931	$6,253	$6,459	$6,843	$7,855	$7,854
Change in Cost for 100% Wt. Red.	$(1,711)	$(2,244)	$(2,606)	$(3,331)	$(6,444)	$(5,843)
	-29%	-36%	-40%	-49%	-82%	-74%
Non-Battery with no ICE credit						
Base Cost	$3,853	$4,281	$4,908	$5,296	$5,863	$6,604
Change in Cost for 100% Wt. Red.	$105	$142	$158	$205	$574	$245
	3%	3%	3%	4%	10%	4%

TABLE A17

EPA Electrification Cost Reduction per Weight Reduction: PHEV20

Curb Weight Class	1	2	3	4	5	6
Battery						
Base Cost	$2,448	$2,591	$2,641	$2,790	$3,024	$3,016
Change in Cost for 100% Wt. Red.	$(441)	$(1,152)	$(504)	$(535)	$(864)	$(865)
	-18%	-44%	-19%	-19%	-29%	-29%
Non-Battery with no ICE credit						
Base Cost	$2,183	$2,403	$2,486	$2,653	$2,968	$2,989
Cost Reduction for 100% Wt. Red.	$46	$61	$68	$88	$107	$114
	2%	3%	3%	3%	4%	4%

TABLE A18

EPA Electrification Cost Reduction per Weight Reduction: PHEV40

Curb Weight Class	1	2	3	4	5	6
Battery						
Base Cost	$3,223	$3,468	$3,614	$3,953	$4,887	$5,009
Cost Reduction for 100% Wt. Red.	$(403)	$(499)	$(565)	$469	$(6,478)	$(8,038)
	-13%	-14%	-16%	12%	-133%	-160%
Non-Battery with no ICE credit						
Base Cost	$2,667	$3,045	$3,195	$3,585	$4,061	$4,165
Cost Reduction for 100% Wt. Red.	$89	$120	$133	$(260)	$209	$(1,005)
	3%	4%	4%	-7%	5%	-24%

The effect of a 100% weight reduction on the cost of either battery or non-battery component costs for each vehicle types (in percentage terms) was applied to the battery and non-battery component costs based on the ICCT projections shown in Tables A8-A12 above to estimate the effect of weight reduction on ICCT-based EV and PHEV costs. The results are shown in Table A19 below.

TABLE A19

Change in EV and PHEV Cost for 100% Weight Reduction

Curb Weight Class	1	2	3	4	5	6
Battery						
EV75	$(394)	$(627)	$(929)	$(512)	$(1,067)	$(1,190)
EV100	$(674)	$(965)	$(1,197)	$(1,809)	$(3,499)	$(3,222)
EV200	$(1,521)	$(1,995)	$(2,317)	$(2,962)	$(5,708)	$(5,186)
PHEV20	$(231)	$(602)	$(264)	$(280)	$(452)	$(453)
PHEV40	$(313)	$(198)	$(225)	$185	$(2,549)	$(3,148)
Non-Battery Components						
EV75	$64	$99	$149	$108	$157	$165
EV100	$69	$98	$101	$137	$174	$167
EV200	$67	$94	$97	$132	$388	$150
PHEV20	$40	$53	$59	$77	$93	$99
PHEV40	$64	$85	$95	$(185)	$149	$(713)

OMEGA Model Projections for 2030 with EPA and ICCT Cost Estimates

2030 EPA Cost and Technology Cap Projections

EPA's analysis in the PD only went through the 2025 model year., the time at which the current CO2 standards stop decreasing. However, since this analysis is focused on CO_2 reductions beyond 2025, it was desirable to use EPA's OMEGA model to determine the impact of lower electrified vehicle costs on achieving CO2 reductions in 2030. This necessitated extending EPA's inputs to the OMEGA model through 2030. Three basic elements of the OMEGA modeling inputs required extension to 2030: vehicle sales, technology costs, and technology caps.

Vehicle sales for the 2030 model year were obtained from EPA. These sales projections apply at the vehicle model level. Overall, fleet-wide vehicle sales increased from 16.4 million in 2025 to 16.7 million in 2030. The sales fraction of passenger cars increased from 28.1% of total vehicle sales in 2025 to 29.6% in 2030. Sales of EVs and PHEVs mandated under the California zero emission vehicle program were increased proportional to total vehicle sales and do not reflect any percentage increase in required sales after 2025 (consistent with the current regulation).

Regarding technology costs, EPA's OMEGA_TechCost_Inputs.xlsx spreadsheet already included learning factors through 2030. Thus, EPA's OMEGA_TechCosts python script was simply run for the model year 2030 in order to generate cost estimates for that year.

Caps on the use of technology were only developed through the 2025 model year in the PD. By 2025, only a few technologies had caps of less than 100%. These are shown in Table A20 below.

TABLE A20

Caps on the Use of Technology by Model Year

Technology	2021	2025	2030
Turbocharged Miller Cycle Engine	30%	75%	100%
Advanced diesel with SCR technology	30%	42%	57%
Cooled EGR	30%	75%	100%
EV75	5.33%	7.68%	10%
EV100	5.33%	7.68%	10%
EV200	5.33%	7.68%	10%
P2 hybrid	30%	50%	75%
48 Volt Mild-hybrid	50%	80%	100%
PHEV-20	7.50%	10.75%	15%
PHEV-40	7.50%	10.75%	15%
24 bar turbocharger	30%	75%	100%

Technology caps were estimated for 2030 by extrapolating the 2025 caps using the rate of change per year between 2021 and 2025, with some minor rounding in a few cases.

OMEGA Model Runs for 2030

Methodology

We attempted to be as consistent as possible in replicating EPA's methodology used to conduct OMEGA modeling in the PD. Where asked, the inclusion of upstream emissions associated with electricity emissions was set to "No". The entire procedure involved the following steps:

1) Adjusting EV and PHEV cost inputs in the OMEGA_TechCost_Inputs spreadsheet for the ICCT Cost modeling. Specifically, the cost of battery and non-battery components (including ICE credit in the case of EVs) were copied into column q of the ev1_dmc_curves worksheet of the OMEGA-TechCost_Inputs spreadsheet. The change in the cost of battery and non-battery components per 100% weight reduction were copied into column p of the ev1_dmc_curves worksheet of the OMEGA-TechCost_Inputs spreadsheet.

2) Creating an OMEGA_TechCosts spreadsheet from the OMEGA_TechCost_Inputs spreadsheet using the TechCosts python script. For the ICCT cost modeling, one additional adjustment was made. The TechCosts python script produced non-battery component costs which were assumed to represent costs in the 2016 model year. As the cost inputs to the OMEGA_TechCost_Inputs spreadsheet were indicative of the 2030 model year, the non-battery component costs in the OMEGA_TechCosts spreadsheet for EVs and PHEVs were adjusted multiplicatively so that the costs for the 2030 model year matched those indicated in Tables 13-18 above.

3) Pasting the new technology costs from the OMEGA_TechCosts spreadsheet to the Machine spreadsheet, taking care to only transfer the “total costs” for each technology

4) Running the Machine spreadsheet to create a partial MasterSet spreadsheet; all “credits” for refrigerant emission control and off-cycle emission reductions were consistent with the PD. The incentive credit for full-hybrid technology usage on trucks was assumed to not apply in 2030

5) Running the MasterSet generator to create a complete MasterSet spreadsheet; in this step, the package list used by EPA in the PD analysis was used without modification

6) The Tech_Ranking_generator was used to create the *_Technology, *_Rank, and *_ScenarioPackages spreadsheets

7) The Machine was run with the *_ScenarioPackages spreadsheet to create a RankedSet Spreadsheet

8) The Market&TechFile_generator was used with the RankedSet spreadsheet to create a Market input file for the OMEGA modeling. Emissions of existing PHEVs and EVs in the market file were set to those which excluded upstream electricity emissions.

9) The Market&TechFile_generator was used with the *_Technology spreadsheet to create a Technology input file for the OMEGA modeling

10) The Scenario input file to the OMEGA model used was the same as that used by EPA in the PD, except that more stringent CO_2 emission reduction Targets were used along with the 2025 footprint based CO_2 standard. Reductions beyond the 2025 standard were generated by subtracting the same CO_2 emission level (e.g., 10 gpm) from the A and B coefficients of both the car and truck standard curves.

11) No changes were made to the Fuels or Reference input files.

12) Finally, the OMEGA model was run in 2030 for a series of CO_2 emission reductions of various stringencies, usually 0, 10, 20, 30, 40, 50, 60, 70, 80, and 90 gpm reductions from the 2025 CO_2 emission standard curves.

Steps 1 and 2 produce estimates of direct manufacturing costs, indirect costs, and total costs (the sum of direct manufacturing costs and indirect costs) for all technologies, including EV and PHEV. Table A21 shows the direct manufacturing costs and total costs for three EVs and two PHEVs using both EPA PD and ICCT-based methodologies for small cars. This provides the most direct comparison of the effect of the ICCT's lower electrified vehicle costs. (The 2030 ICCT costs shown here differ slightly from those shown above in Table 2. This is due to the translation of ICCT cost projections for 2030 back to 2017 and 2029/2030 for non-battery and battery costs, respectively, using EPA learning multipliers and then the reapplication of these factors within EPA modeling tools for the generation of 2030 costs.)

TABLE A21

Comparison of EPA and ICCT Costs for Small Cars with No Weight Reduction

	EPA PD to 2030	ICCT 2030	Difference
Direct Manufacturing Cost excluding Charger			
EV75	$3,680	$235	$(3,445)
EV100	$4,153	$1,078	$(3,075)
EV200	$5,782	$3,715	$(2,868)
PHEV20	$4,132	$3,172	$(959)
PHEV40	$5,279	$4,458	$(821)
Indirect Costs			
EV75	$1,968	$2,038	$70
EV100	$2,204	$2,256	$52
EV200	$3,016	$3,571	$555
PHEV20	$1,954	$1,462	$(491)
PHEV40	$2,502	$2,070	$(432)
Total Costs excluding charger (Direct Manufacturing Cost plus Indirect Costs)			
EV75	$5,649	$2,273	$(3,375)
EV100	$6,357	$3,334	$(3,023)
EV200	$8,798	$7,286	$(1,512)
PHEV20	$6,085	$4,635	$(1,451)
PHEV40	$7,781	$6,461	$(1,320)

As can be seen, the ICCT-based direct manufacturing costs for EVs range from $2900-3400 cheaper depending on range. The differences for the two PHEVs are much smaller at $800-1000 per vehicle. These differences increase for the EV75, PHEV20 and PHEV40 at the total cost level. However, the difference in EV100 and EV200 costs at the total cost level are actually smaller than at the direct manufacturing level. The difference between direct manufacturing and total costs is the addition of indirect costs. Normally, indirect costs are a specified percentage of direct manufacturing costs. Thus, differences at the direct manufacturing cost level become even larger at the total cost level.

This is the case for the two types of PHEVs. The indirect cost multiplier for PHEV technologies is roughly 1.5 (indirect costs are 0.5 times direct manufacturing costs). This explains why the difference in PHEV manufacturing costs is 50% larger at the total cost level. However, it is not the case for the EVs.

While the indirect cost multiplier for EV technologies is also roughly 1.5, there is an added stipulation made by EPA in the OMEGA model that if the direct manufacturing cost is negative, it is assumed to be positive for the determination of the indirect cost. As discussed above, the cost of EV technology is split into two parts: battery costs and all other costs. The battery cost is always positive. However, the non-battery costs include the credit for replacement of the conventional engine and transmission. In some cases, the net non-battery cost is negative. However in this case, the model considers the indirect cost to be positive. It is reasonable for indirect costs to increase to some degree in this case, as the development of new electric drivetrains and electronic management systems will require development, warrantees, etc. However, the simple exchange of a negative sign to a positive sign means that the larger the negative direct manufacturing costs, the larger the associated indirect cost. This is counter intuitive. For example, as the cost of non-battery components declines over time, the associated indirect costs would be projected to rise. It thus seems prudent to develop some other methodology for the estimation of indirect costs in this case. One possibility would be to split the non-battery components into two parts, one including all of the new electrical components, the other including the conventional drivetrain which is being replaced. Each part could be assigned its own indirect cost multiplier. The multiplier representing the new electrical components would have a higher multiplier as it is addressing new technology. The multiplier representing the replacement of the conventional drivetrain would have a smaller multiplier as this is mature technology.

We retained EPA's current approach in our processing of the PHEV and EV costs here. This explains why the indirect costs for EVs with lower ICCT-based costing are actually higher than those for the same EVs with higher EPA-based costing. This is especially true for EV200s. The net effect of EPA's indirect cost estimation procedure is that it mutes the cost reductions which ICCT projects will accrue over time at the direct manufacturing level.

EPA PD Projection Extended to 2030

This analysis is intended to be as consistent as possible with EPA's PD analysis methodology. As described above, three sets of inputs were extended to 2030: vehicle sales, technology cost and technology caps. All of these values were already contained in the EPA files and programs used to produce the OMEGA input files. We focus on four specific outputs of the OMEGA model: technology costs per vehicle, the overall use of key technologies fleet-wide and for selected manufacturers, the payback period required to recover up-front vehicle costs, and the total discounted fuel savings over the life of the average vehicle. All outputs of the OMEGA model and its pre- and post-processors are available upon request.

Two “EPA Cost” scenarios were evaluated. In the first scenario, the technology caps for EV and PHEV technology were set at zero to evaluate what additional CO_2 reductions could be achieved without relying on ZEV technologies. Any use of ZEV technologies in the baseline fleet was retained. In the other scenario, the technology caps were set as described in Table 20 above.

In addition to these two EPA cost scenarios, a third scenario which utilized ICCT cost projections for EV/PHEV technology was evaluated. In this scenario, the technology caps were also set as described in Table 20 above. It should be pointed out that we continued to only account for tailpipe CO_2 emissions (no upstream emissions) for 2030, as EPA did in the PD until 2025.

Table A22 shows the fleet-wide average emission levels required under various CO_2 emission reductions for cars, trucks and cars and trucks combined. “FRM Stds” is shorthand notation for the 2025 standards established by EPA in its 2012 final rule. The 2025 standards produce a fleet-wide CO_2 emission level of 173 gpm given the updated fleet mix projected in the PD for 2025 in the final rule. This level is not directly required by the standards, however, as the actual footprint distributions for cars and trucks, respectively, and the mix of cars and trucks could change. Also, EPA projects that roughly 23 gpm of “credits” will be generated by manufacturers from refrigerant emission controls and off-cycle emission controls. These credits are considered outside of the OMEGA modeling. Thus, the 2025 standard used in the OMEGA modeling reflects a fleet-wide average emission level of roughly 196 gpm versus the official projection of 173 gpm. All of these emission levels apply to the projected 2025 model year fleet. While the vehicles EPA projects to be sold in 2030 differ from those in 2025, the net effect of these changes cancel and the fleetwide average CO_2 levels required by the 2025 standards remain essentially constant. The more stringent emission reductions we modeled reflect increments of 10 gpm of emission reduction from the levels of the FRM standards level. The 10 gpm reductions were applied consistently to both cars and trucks.

Table A22 shows the fleet-wide emission levels achievable when manufacturers do not have access to additional EV or PHEV technology. Levels achievable by individual manufacturers are discussed in the main body of the report.

TABLE A22

Emissions Under The "No EV/PHEV Scenario – 2030 (gpm) – More discussion in body of report

	Target CO_2 Emissions			Achieved CO_2 Emissions		
Target	Car	Truck	Combined	Car	Truck	Combined
FRM Stds	165.96	226.41	195.56	171.41	218.04	194.43
-10 g	155.96	216.41	185.56	163.38	206.52	184.68
-20 g	145.96	206.41	175.56	155.90	196.31	175.85
-30 g	135.96	196.41	165.56	149.64	184.88	167.04
-40 g	125.96	186.41	155.56	142.24	176.44	159.12
-50 g	115.96	176.41	145.56	137.04	170.79	153.70
-60 g	105.96	166.41	135.56	136.05	170.03	152.83
-70 g	95.96	156.41	125.56	136.05	170.03	152.83

As can be seen Table 22, the fleet average compliance level is below that required by a 10 gpm reduction from the 2025 standards and is nearly below that required by a 20 gpm reduction. However, significant shortfalls on a fleet-wide basis begin to occur with a 30 gpm reduction.

Table 23 shows the levels of CO_2 emissions achieved when EVs and PHEVs are available but capped at the relatively low levels projected in the PD and linearly extrapolated to 2030.

TABLE A23

Emissions With EV/PHEVs Capped at EPA "2030 PD Levels"* (Table 20) – 2030 (gpm)

	Target CO_2 Emissions(gpm)			Achieved CO_2 Emissions (gpm)		
Target	Car	Truck	Combined	Car	Truck	Combined
FRM Stds	165.96	226.41	195.56	173.59	215.86	194.46
-10 g	155.96	216.41	185.56	165.16	204.02	184.34
-20 g	145.96	206.41	175.56	156.63	192.84	174.51
-30 g	135.96	196.41	165.56	149.49	179.94	164.53
-40 g	125.96	186.41	155.56	140.03	169.55	154.60
-50 g	115.96	176.41	145.56	131.03	159.01	144.84
-60 g	105.96	166.41	135.56	118.19	151.50	134.64
-70 g	95.96	156.41	125.56	109.14	140.71	124.73
-80 g	85.96	146.41	115.56	96.50	133.65	114.84
-90 g	75.96	136.41	105.56	87.50	123.54	105.30

* This scenario not discussed in body of report

As can be seen, by allowing limited use of EV and PHEV technology, greater CO_2 reductions can be achieved. On a fleet-wide average basis, CO_2 emissions can be reduced by 90 gpm relative to the 2025 standards.

Looking at specific manufacturers, all manufacturers are able to comply with up to an 80 gpm emission reduction. With a 90 gpm CO_2 reduction, a couple of manufacturers cannot comply under the extrapolated EPA caps for technology. This applies regardless of EV cost, as cost doesn't affect the ability to comply, only the cost to do so.

Table A24 shows the technology which the OMEGA model projects would be applied to achieve the emission levels shown for the three scenarios that limit EV/PHEV use.

TABLE A24

Fleet-Wide Technology Use Under Three Scenarios w/Caps on EV/PHEV Use

	Atkinson 2	Turbo. Miller	Mild Hybrid	Full Hybrid	EV+ PHEV	24 Bar Turbo Downsize	Cyl Deact.	Start-Stop	Wt. Red.
EPA Costs, No EVs									
FRM Stds	26.3%	3.1%	20.9%	2.2%	4.4%	7.2%	48.9%	12.9%	8.6%
-10 g	44.3%	8.6%	28.6%	2.2%	4.1%	13.6%	57.7%	20.8%	9.2%
-20 g	57.8%	12.5%	40.8%	3.4%	4.1%	18.0%	62.3%	24.1%	10.5%
-30 g	65.6%	26.0%	52.9%	3.9%	4.1%	24.9%	63.5%	35.8%	11.5%
-40 g	73.5%	49.9%	68.9%	7.7%	4.1%	20.4%	73.5%	19.4%	13.5%
-50 g	83.2%	77.0%	84.8%	10.3%	4.1%	10.6%	83.2%	0.8%	14.7%
-60 g	85.6%	85.6%	85.6%	10.3%	4.1%	8.2%	85.7%	0.0%	15.0%
-70 g	85.6%	85.6%	85.6%	10.3%	4.1%	8.2%	85.7%	0.0%	15.0%
EPA EV/PHEV Costs - EPA EV/PHEV Caps									
FRM Stds	20.5%	0.2%	12.9%	2.2%	5.0%	4.8%	43.4%	16.0%	8.2%
-10 g	36.5%	0.4%	20.3%	2.2%	5.9%	8.1%	53.6%	23.1%	8.7%
-20 g	46.1%	0.9%	29.0%	2.2%	7.5%	14.0%	53.5%	25.8%	9.4%
-30 g	50.5%	1.5%	30.1%	2.1%	10.0%	22.8%	55.0%	40.7%	9.8%
-40 g	51.6%	2.9%	31.1%	2.1%	14.1%	21.8%	54.5%	44.9%	10.7%
-50 g	51.5%	5.3%	34.6%	2.1%	17.9%	25.5%	52.1%	45.4%	11.3%
-60 g	51.0%	8.6%	38.1%	2.0%	23.0%	23.8%	47.5%	36.9%	11.8%
-70 g	48.4%	13.3%	36.2%	6.8%	27.7%	22.1%	47.9%	29.4%	12.9%
-80 g	46.6%	28.4	48.5%	9.7%	32.5%	19.3%	46.7	9.3%	13.8%

		%					%		
-90 g	47.1%	40.2 %	48.0%	9.6%	40.5%	11.0%	47.1%	1.9%	14.3%
ICCT EV/PHEV Costs - EPA EV/PHEV Caps									
FRM Stds	13.4%	0.0%	3.9%	2.2%	7.4%	0.4%	36.2 %	16.3%	7.9%
-10 g	19.9%	0.0%	10.6%	2.2%	9.8%	0.4%	42.8 %	17.5%	8.2%
-20 g	32.4%	0.0%	15.6%	2.1%	12.3%	1.4%	48.8 %	16.9%	8.6%
-30 g	37.4%	0.5%	22.8%	2.1%	15.6%	5.7%	48.4 %	14.7%	9.1%
-40 g	41.3%	0.8%	25.8%	2.0%	19.0%	10.7%	48.1%	17.8%	9.7%
-50 g	45.2%	2.8%	28.3%	1.8%	21.9%	18.2%	48.0 %	26.9%	10.3%
-60 g	45.5%	4.8%	30.8%	1.7%	25.0%	24.6%	45.8 %	39.4%	11.1%
-70 g	48.1%	9.9%	33.8%	3.1%	29.5%	20.5%	45.8 %	33.5%	12.2%
-80 g	39.6%	10.2%	31.6%	9.3%	35.7%	23.3%	39.6 %	23.5%	13.3%
-90 g	37.0%	20.6 %	38.4%	9.5%	43.9%	17.8%	37.0 %	8.3%	14.1%

While not shown in the table, use of PHEV technology is very low in all three scenarios. In the no EV/PHEV scenario, it of course remains at baseline levels of about 2%. In the two capped EV scenarios, PHEV technology remains at 2% until about a 60 gpm reduction. At this point the caps on EV technologies begin to be reached, and PHEVs begin to be selected to achieve additional CO_2 reduction. With a 90 gpm reduction, PHEV technology has reached 12% with the EPA costs and 16% with the ICCT costs.

As can be seen, when no EVs or PHEVs are available, the model projects most cars and trucks will be equipped with turbocharged Miller cycle engines and mild hybrid systems, along with the maximum allowed reduction in vehicle weight. The technology penetrations level off at the -50/-60 gpm reduction level, at which point the most capable manufacturer has utilized all of the applicable technologies that the model considers available. At the other end of the spectrum, several manufacturers have utilized all available technologies before achieving a 20 gpm reduction level. (The OMEGA model tracking of technology considers Miller cycle to be a variant of Atkinson 2 technology, so engines which initially receive Atkinson 2 technology and go on to Miller cycle technology continue to be considered Atkinson 2 engines, as well.)

It is interesting that few vehicles move from mild hybridization to full hybridization despite the model running out of technology to facilitate compliance with the more stringent reductions in the no-EV/PHEV scenario. This is due to the fact that full hybrid technology packages are not generally selected through EPA's technology ranking process. (Or, if full hybrid technology packages are selected in the middle of the technology application process, they are supplanted later by mild hybrid packages as the CO_2 reductions required increase.) The reason for this is the fact that EPA's complete list of over 6000 technology packages for each of the 29 vehicle types usually contains mild hybrid packages which achieve greater emission reductions than the best full hybrid packages. Since mild hybridization tends to be cheaper than full hybridization, the ranking process will not include a full hybrid package if it is both less effective and more costly than a particular mild hybrid package. A review of the final ranked set of technology packages developed for input to the OMEGA model for the above three scenarios shows that only vehicle types 8, 9, 22, 25, and 29 included a full hybrid package. These five vehicle types represent just over 10% of fleet-wide car and truck sales in 2030, and thus, the 10.3% peak for full hybrid penetration across the three scenarios.

We investigated why the best mild hybrid packages usually produce greater emission reductions than best full hybrid packages. Part of the OMEGA model preprocessing procedure is to estimate both emission control effectiveness and cost of each of over 6000 technology packages for each of the 29 vehicle types. EPA refers to these estimates as Master Sets. Using the Master Set for the 2025 model year control scenario with mid-range AEO projections from the PD analysis, we ranked the technology packages for each of the 29 vehicle types by total emission control effectiveness. We then examined the most effective technology packages excluding PHEV and EV packages. For 20 out of the 29 vehicle types, the most effective technology package was a mild hybrid package. The first half of Table A25 lists these 20 vehicle types and shows the specific technologies which do not appear in both the best mild and full hybrid packages. (Technologies included in both packages are not shown, as they are not the cause of the difference in effectiveness or cost.) The primary reason why the mild hybrids outperform the full hybrids is that they include a more efficient engine, especially a turbocharged Miller cycle engine with cylinder deactivation versus a phase 1 Atkinson cycle engine with dual variable valve lift in the full hybrid packages.

The second possible reason the best mild hybrid packages outperform the best full hybrid packages is that the mild hybrid packages include either the first phase of off-cycle credits (OC1) or the second phase of off-cycle credits (OC2) As it turns out, the best mild hybrid package without the off-cycle credits still outperforms the best full hybrid package

The mild hybrid packages also include phase 2 improvements to the air conditioning system versus only phase 1 air conditioning improvements for the full hybrid packages, according to this table derived from OMEGA. However, upon further examination the second phase of air conditioning improvements is automatically included by EPA in the effectiveness of full hybridization, even though the A/C 2 designator does not appear in the technology package description. Thus, the difference in effectiveness between mild and full hybrids is mainly due to differences in engine efficiency.

TABLE A25

Technologies Combined with Mild and Full Hybrid Technology in EPA PD Modeling

Best Mild Hybrid Technology Package More Effective Than the Best Full Hybrid Package		
Vehicle Type	Technologies with Best 48V Mild Hybrid	Technologies with Best Full Hybrids
1, 2, 3, 5, 10, 11, 12, 13, 14, 15, 16, 18, 19, 20, 21, 23, 24, 26, 27, 28	Turbo. Miller, Deac, Cooled EGR, Improved A/C 2, Off-cycle credits 2	Atkinson 1, Improved A/C 1, DVVL
Best Full Hybrid Technology Package More Effective Than the Best Mild Hybrid Package		
4, 6, 7, 17	Turbo. Miller, Deac, Cooled EGR, Improved A/C 2, Off-cycle credits 2	Atkinson 1, Improved A/C 1, DVVL
8, 9, 22, 25, 29	Turbo. Miller, Deac, Cooled EGR, Improved A/C 2, Off-cycle credits 2	24 bar, Turbo-downsized GDI, Cooled EGR, Improved A/C 1, DVVL

For the remaining nine vehicle types, full hybrid packages outperform the best mild hybrid packages. These vehicle types are listed in the second half of Table A25. For four vehicle types, #4, 6, 7, and 17, the specific technologies of the best mild and full hybrid packages are exactly the same as those for the 20 vehicle types discussed above. The difference for these four vehicle types is that the best full hybrid packages now outperform the best mild hybrid packages, rather than the other way around. It should be pointed out that the difference between the best mild hybrid package and best full hybrid package, or vice versa, is at most 1%. Thus, the shift in relative effectiveness is only 2% or so. The difference between these four vehicle types and the other 20 is that the four involve vehicles having both a low power to weight ratio and a high road load. These differences in the base vehicle characteristics appear to shift the relative effectiveness of the mild and full technology packages.

The other five vehicle types for which the best full hybrids outperform the best mild hybrids (8, 9, 22, 25, 29) are all considered “trucks” with respect to EPA’s estimation of technology effectiveness and comprise those vehicles with heavy towing capability. For these vehicles, the mild hybrid technologies are the same as those applied to the other 24 vehicle types. However, the engines utilized with full hybridization differ and now include a downsized, gasoline fueled, direct injection engine with a 24 bar turbocharger with cooled EGR. The best full hybrid packages for these five vehicle types outperform the best mild hybrid packages again by at most 1%, as was the case above. For these “heavy-towing” vehicles, the total effectiveness of both the best mild and full hybrid packages drops relative to the other vehicle types. However, the effectiveness of the best mild hybrid package drops more than that of the best full hybrid package, making the full hybrid package the better of the two.

Table A26 shows the absolute emission control effectiveness and cost of both the best mild and full hybrid packages for several vehicle types. The specific engine technologies are those listed in Table A25 above.

TABLE A26

Comparison of the Emission Control Effectiveness and Cost of the Best Mild and Full Hybrid Packages by Vehicle Type

Vehicle Type	Best Mild Hybrid		Best Full Hybrid	
	Emission Control Effectiveness	Cost	Emission Control Effectiveness	Cost
1	55.7%	$3,966	55.6%	$4,922
2	56.6%	$3,914	56.6%	$4,957
3	56.7%	$3,959	56.6%	$5,197
4	54.7%	$4,056	55.5%	$5,206
5	56.9%	$3,999	56.4%	$5,311
6	54.8%	$4,094	55.2%	$5,319
7	54.8%	$4,155	55.5%	$5,494
8	58.0%	$5,180	59.0%	$7,675
9	58.3%	$7,117	59.0%	$8,453
10	62.1%	$5,298	60.9%	$5,916
11	58.4%	$5,391	57.5%	$6,123
12	55.7%	$4,955	55.6%	$5,304
13	56.9%	$4,995	56.6%	$5,538
14	55.8%	$5,013	55.6%	$5,556
15	61.5%	$5,043	60.3%	$5,660
16	57.0%	$5,073	56.4%	$5,691
17	54.8%	$5,085	55.2%	$5,703
18	61.5%	$5,124	60.5%	$5,857
19	57.6%	$5,126	56.6%	$5,858
20	61.5%	$5,197	60.5%	$6,203
21	57.6%	$5,222	56.6%	$6,229
22	58.0%	$6,218	59.0%	$7,499
23	62.1%	$6,212	61.0%	$7,188
24	58.4%	$6,292	57.5%	$7,268
25	58.3%	$7,483	59.0%	$9,458
26	61.5%	$5,375	60.5%	$6,077
27	61.5%	$5,536	60.5%	$6,512
28	57.6%	$5,597	56.6%	$6,573
29	58.0%	$6,753	59.0%	$8,824

The best full hybrid packages cost roughly $700-2000 more than the best mild hybrid packages. The difference in emission control effectiveness ranges from 0.5-1.0% and can go in either direction. When the best mild hybrid packages outperform the best full hybrid packages, the full hybrid packages are never included in the final set of ranked technology packages, as the OMEGA model will not project that manufacturers would increase vehicle cost to reduce emission control effectiveness. Even when the best full hybrid packages outperform the best mild hybrid packages, their incremental cost effectiveness is not particularly good compared with vehicle electrification. When either PHEV or EV packages are available for application to a particular vehicle type, the incremental cost effectiveness of these electrified vehicles relative to the best mild hybrid package is better than that of moving to the best hybrid package. Thus, for all vehicle types other than 8, 9, 22, 25, and 29, until PHEVs and EVs reach their caps on use, full hybrid technology will generally not be selected. Full hybrid technology will generally only be selected for the heavy towing vehicles when a manufacturer is projected to need to apply the best emission control technology available to a particular vehicle. (Also note the model does not consider EV or PHEVs as applicable to heavy towing capable vehicles).

Discussions with EPA staff indicate that better engines could have been included as part of the full hybrid packages. This was not done in the PD analyses due to the expected poor relative cost effectiveness of this step, as well as the fact that few manufacturers, if any, needed such technology in order to meet the 2025 standards. In general, however, some degree of further emission control could be achieved when EV/PHEVs are not available if full hybrids using more advanced engines, but at a cost effectiveness inferior to using mild hybrids.

Returning to discussing the three CO_2 control scenarios described thus far, the two scenarios in which EV and PHEV technology is available to be added to vehicles show EV technology is chosen even at the level of the current 2025 standard. While non-EV/PHEV technology would provide sufficient emission reductions to reach this level of control, the OMEGA model projects that EV/PHEV technology in 2030 would be a more cost effective approach for some manufacturers' models. This occurs with either EPA or ICCT costs estimates, though the level of EV use is greater with the ICCT lower cost estimates. EVs penetrate the fleet before PHEVs, as they are more cost effective.

Table A27 shows the average, fleet-wide increase in total vehicle price (manufacturing and indirect costs, and charging infrastructure for EVs) for the three scenarios discussed thus far. For EVs, these total costs also include the cost of a home charging system and installation.

TABLE A27

Increase in Average Vehicle Price in 2030 of Achieving CO_2 Emission Reductions Relative to the 2015 Reference Fleet ($/vehicle)

	No Additional EV/PHEVs	Caps Limiting EV/PHEV Selection - in 2030	
		EPA EV/PHEV Costs	ICCT EV/PHEV Costs
FRM Stds	$1,257	$1,175	$1,047
-10 gpm	$1,665	$1,497	$1,241
-20 gpm	$2,115	$1,844	$1,470
-30 gpm	$2,589	$2,216	$1,716
-40 gpm	$3,222	$2,574	$2,008
-50 gpm	$3,772	$2,996	$2,368
-60 gpm	$3,905	$3,405	$2,773
-70 gpm	$3,905	$4,014	$3,265
-80 gpm	--	$4,687	$3,901
-90 gpm	--	$5,456	$4,486

As can be seen, the least cost options to achieve any of the levels of CO_2 reduction are the scenarios that allow EV/PHEVs to be selected. This is true even with the higher EV/PHEVs costs assumed by EPA. The differences start out around $100 per vehicle at the level of the 2025 standards and increase with increasing levels of CO_2 emission reduction. The increase in vehicle cost under the no EV/PHEV scenario beyond -30 g gpm CO_2 start leveling off and are no longer comparable to those of the other two scenarios, as more and more manufacturers fail to be able to achieve the higher levels of reduction with using EVs/PHEVs. Among the two EV/PHEV scenarios which allow limited selection of EV/PHEVs by the model, the savings associated with the ICCT cost estimates reaches $1000 per vehicle when averaged across the entire fleet.

Increased Availability and Use of EV/PHEV Technology

We evaluated two additional scenarios of increased EV and PHEV use. The first scenario is dubbed the 'EV100' scenario, while the second is dubbed the 'EV200' scenario. In both scenarios, EV technology is assumed to be available with no limitations (i.e no caps) for all vehicles except for those designed to perform heavy towing. These are the same vehicles which EPA assumes can be electrified. Non-heavy towing vehicles represent about 89% of total vehicle sales in 2030.

Under the 'EV100' scenario, a 100 mile range is assumed to be sufficient for all nonheavy-towing vehicles. The cap for the EV100 package was set at 100%. The cap for the EV75 package was set at zero, so that the OMEGA model would progress through its ranked list of technology packages to the EV100 package. Under the 'EV200' scenario, a 200 mile range is assumed to be required by purchasers of non-towing vehicles. The technology caps for EV75 and EV100 packages were set at zero. PHEV technology is never chosen under these two scenarios, as the model stops adding technology once tailpipe emissions are zero and PHEV technology is always more expensive than EV100 or EV200 technology.

When evaluating these two EV scenarios, the effect of both EPA and ICCT based costs for EVs were considered. This produced four sets of OMEGA modeling runs evaluating the full set of CO2 emission reduction levels in each case.

With the non-constrained availability of EV technology for 60% of vehicle sales, achieving an -90 gpm CO_2 reduction is possible for most vehicle manufacturers.

Table A28 shows the penetration of key technologies under for the two sets of EV costs for the EV100 scenario.

TABLE A28

Fleet-Wide Technology Use Under the 'EV100 only' Scenario

Fleet Average	Atkinson 2	Turbo. Miller	Mild Hybrid	Full Hybrid	BEV+ PHEV	24 Bar Turbo Downsize	Cyl. Deact	Start - Stop	Wt. Red.
EPA EV Costs									
FRM Stds	18.4%	0.2%	12.3%	2.2%	5.1%	4.7%	41.4%	13.7%	8.1%
-10 gpm	33.7%	0.4%	18.8%	2.2%	5.9%	7.8%	50.8%	22.0%	8.5%
-20 gpm	42.8%	0.8%	26.0%	2.2%	7.9%	9.9%	50.1%	21.1%	9.0%
-30 gpm	45.0%	0.8%	22.8%	2.1%	10.9%	15.2%	50.7%	32.5%	9.6%
-40 gpm	43.9%	0.8%	22.2%	2.1%	14.9%	16.8%	49.0%	36.4%	10.1%
-50 gpm	42.9%	0.8%	22.3%	2.1%	19.2%	18.5%	47.1%	37.8%	10.5%
-60 gpm	41.4%	0.8%	21.5%	2.1%	24.3 %	17.1%	44.6%	34.2%	10.8%
-70 gpm	39.1%	0.8%	20.1%	2.0%	29.2 %	15.9%	42.3%	36.8%	11.0%
-80 gpm	36.7%	0.8%	18.4%	2.0%	34.3 %	16.4%	39.9%	33.6%	11.2%
-90 gpm	34.7%	0.8%	16.1%	2.0%	39.3 %	14.2%	37.3%	34.1%	11.5%
ICCT EV Costs									
FRM Stds	11.3%	0.0%	1.8%	2.2%	7.0%	0.0%	35.5%	17.0%	7.8%
-10 gpm	18.6%	0.0%	2.4%	2.1%	9.5%	0.2%	42.6%	22.3%	8.0%
-20 gpm	26.6%	0.0%	2.4%	2.1%	12.4%	0.2%	44.7%	24.2%	8.3%
-30 gpm	27.5%	0.0%	5.5%	2.1%	16.6%	0.2%	45.1%	19.6%	8.7%
-40 gpm	27.0%	0.0%	7.9%	2.1%	20.5 %	0.2%	42.2%	15.7%	9.0%
-50 gpm	27.9%	0.0%	7.9%	2.1%	24.5 %	0.2%	41.3%	14.0%	9.4%
-60 gpm	27.4%	0.0%	7.9%	2.0%	29.0 %	0.2%	40.3%	12.2%	9.8%
-70 gpm	28.4%	0.0%	9.2%	2.0%	33.4 %	0.2%	38.9%	9.7%	10.2%
-80 gpm	31.1%	0.0%	9.6%	2.0%	37.9%	0.2%	39.2%	9.7%	10.6%
-90 gpm	32.3%	0.0%	10.4%	2.0%	42.7%	0.2%	37.3%	9.2%	10.9%

As can be seen, the projected technology usage with the two different EV cost estimates shows very similar trends. In general, EV penetration is higher and non-EV technology use is lower with the ICCT lower EV costs than with the higher EPA EV costs. This occurs because the ICCT's lower EV cost pushes EV technologies higher up the ranked technology list than if EPA's cost is used, bypassing one or more non-EV technologies packages. Thus an EV100 package may be preferentially chosen when needed to achieve the next increment of CO_2 reduction, compared to the higher cost EPA scenario where a conventional technology might be applied. At the final -90 gpm control level shown here, EV/PHEV use reaches 39% with EPA EV costs and 43% with the lower ICCT costs.

Table A29 presents the same information for the EV200 scenario.

TABLE A29

Fleet-Wide Technology Use Under the 'EV200 only' Scenario

Fleet Average	Atkinson 2	Turbo. Miller	Mild Hybrid	Full Hybrid	EV + PHEV	24 Bar Turbo. Down-Size	Cyl. Deact.	Start - Stop	Wt. Red.
EPA EV Costs									
FRM Stds	21.2%	0.2%	15.5%	2.2%	4.6%	6.5%	44.2%	13.5%	8.2%
-10 gpm	36.2%	0.4%	21.4%	2.2%	5.1%	12.5%	52.9%	24.1%	8.9%
-20 gpm	50.6%	2.2%	33.6%	2.2%	5.6%	18.1%	54.6%	29.9 %	9.5%
-30 gpm	53.6%	2.2%	31.9%	2.1%	7.8%	26.7%	56.2%	51.9%	10.5%
-40 gpm	53.5%	2.9%	33.7%	2.1%	11.4%	27.5%	55.5%	52.8 %	11.0%
-50 gpm	52.1%	2.9%	31.7%	2.1%	15.8%	25.9%	53.6%	50.3 %	11.7%
-60 gpm	53.0%	5.3%	29.2%	2.1%	20.3%	23.9%	49.4%	48.4 %	11.9%
-70 gpm	53.2%	8.2%	26.1%	2.0%	25.5%	18.6%	49.7%	46.4 %	12.0%
-80 gpm	49.8%	8.0%	23.2%	2.1%	31.0%	16.6%	46.2%	43.6 %	12.3%
-90 gpm	47.3%	8.0%	20.0%	2.1%	36.5%	13.6%	43.6%	41.4%	12.5%
ICCT EV Costs									
FRM Stds	18.4%	0.2%	13.4%	2.2%	5.0%	4.8%	41.5%	13.0%	8.1%
-10 gpm	34.2%	0.4%	20.3%	2.2%	5.4%	9.5%	51.3%	22.5 %	8.8%
-20 gpm	43.8%	0.8%	27.6%	2.2%	7.2%	12.9%	50.8%	21.8%	9.3%
-30 gpm	47.1%	0.8%	25.3%	2.1%	9.8%	19.5%	52.3%	41.4%	9.9%
-40 gpm	46.9%	1.4%	24.4%	2.1%	13.4%	21.3%	50.1%	46.7 %	10.4%
-50 gpm	46.6%	1.4%	24.6%	2.1%	17.3%	24.5%	49.3%	51.0%	10.8%
-60 gpm	46.9%	2.8%	23.3%	2.1%	22.3%	20.6%	48.2%	47.5%	11.1%
-70 gpm	47.0%	2.8%	20.1%	2.0%	27.3%	17.1%	48.3%	46.3 %	11.4%
-80 gpm	44.7%	2.8%	17.6%	2.0%	32.6%	14.8%	45.9%	45.1%	11.6%
-90 gpm	42.3%	2.9%	16.9%	2.0%	37.8%	13.4%	43.5%	43.2 %	12.0%

Comparing the EV200 scenario to the EV100 scenario, EV penetration in the EV200 scenario is less and conventional technology penetration greater. This occurs because the manufacturing cost of an EV200 is $1600 to $2600 higher than an EV100. As a result more conventional technologies are selected by OMEGA before an EV200 is selected, compared to the EV100 scenario.

Table A30 shows the increase in total vehicle price (manufacturing and indirect costs, and charging infrastructure for EVs) for both the EV100 and EV200 scenarios and both EPA and ICCT EV costs.

TABLE A30

Increase in Average Vehicle Price in 2030 of Achieving CO_2 Emission Reductions Relative to the 2015 Reference Fleet ($/vehicle)

	EV100 Scenario		EV200 Scenario	
	EPA EV Costs	ICCT EV Costs	EPA EV Costs	ICCT EV Costs
FRM Stds	$1,152	$1,044	$1,195	$1,162
-10 gpm	$1,462	$1,240	$1,535	$1,492
-20 gpm	$1,776	$1,434	$1,933	$1,824
-30 gpm	$2,099	$1,609	$2,364	$2,193
-40 gpm	$2,411	$1,783	$2,794	$2,562
-50 gpm	$2,758	$1,971	$3,231	$2,948
-60 gpm	$3,084	$2,160	$3,695	$3,318
-70 gpm	$3,413	$2,350	$4,183	$3,707
-80 gpm	$3,712	$2,529	$4,586	$4,032
-90 gpm	$4,064	$2,714	$5,076	$4,424

The change of the price for each 10 gram increment of CO_2 reduction gives an indication how the cost effectiveness of reducing emissions varies as the overall amount of CO_2 reduction increases from 10 to 90 gpm. For the EV100 scenarios shown above, the cost of a 10 gpm reduction is near constant over a 90 gpm reduction, for both EPA and ICCT cost estimates. The cost for a 10 gpm reduction is roughly $300 with the EPA EV100 costs and $200 with the ICCT EV100 costs.

For the EV200 scenario, the cost per 10 gpm reduction steadily increases as a 90 gpm reduction is reached. The cost per 10 gpm reduction increases from $340 to $490 with EPA EV200 costs and from $330 to $390 with the ICCT EV200 costs.