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# Economic Impacts of Major California Climate Change Goals

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## EXECUTIVE SUMMARY

The California Air Resources Board (ARB) is in the process of developing an updated Scoping Plan that will propose specific regulatory approaches to achieve the Governor's 2030 greenhouse gas emissions (GHG) reduction target. As in its earlier Scoping Plan[1] to achieve the 2020 emissions reduction target, the ARB may choose among many regulatory tools and measures to achieve the 2030 target. The California Manufacturers & Technology Association (CMTA) commissioned NERA Economic Consulting (NERA)[2] to conduct a study of the potential economic impacts of the various choices of California's climate policies on California's economy and households. NERA[3] relied upon publicly available information and NERA's proprietary energy-economic model, $N_{ew}$ERA, to conduct the analysis.

In assessing the choices before the ARB, NERA designed its analysis to answer three important questions:

- How does the cost-effectiveness of ARB's 2030 Scoping Plan proposal compare to plans that would include a different mix of emission reduction measures and targets?
- How do different designs and targets for the low carbon fuel standard (LCFS) affect the cost to reduce greenhouse gas emissions from transportation fuels and impact California's economy overall?
- How does including or excluding offsets[4] in the cap-and-trade program affect the cost of reducing emissions?

[1] The first Scoping Plan was approved in 2008. In 2011, the Scoping Plan was re-approved by the Air Resources Board. http://www.arb.ca.gov/cc/scopingplan/document/scopingplandocument.htm

[2] NERA is a global firm of experts dedicated to applying economic, finance, and quantitative principles to complex business and legal challenges. For over half a century, NERA's economists have been creating strategies, studies, reports, expert testimony, and policy recommendations for government authorities and the world's leading law firms and corporations. NERA brings academic rigor, objectivity, and real world industry experience to bear on issues arising from competition, regulation, public policy, strategy, finance, and litigation. NERA's Energy, Environment, and Network Industries (EEN) group has extensive experience modeling economic impacts from energy and environmental policies, including analysis of the Federal government's Clean Power Plan (CPP) and California's AB 32.

[3] All results and observations are based on information at the time of the report. To the extent that additional information becomes available or the factors upon which our analysis is based change, our opinions could subsequently be affected.

[4] Offsets refer to emission reductions that occur outside California's cap-and-trade system.

## Study Methodology and Key Results

To examine these three questions, this study employs NERA's proprietary $N_{ew}$ERA modeling system[5] to analyze a number of scenarios that all achieve the Governor's 2030 emissions target of 40% below 1990 levels. To reflect existing law, all scenarios assume an economy-wide cap-and-trade program,[6] a 50% renewable portfolio standard (RPS) target, and a doubling of energy efficiency in commercial buildings by 2030.

To reflect the range of policies that may be included in the updated Scoping Plan, this study considers scenarios that vary in their use of transportation sector specific measures and targets – LCFS, a petroleum reduction target, and zero emissions vehicle (ZEV) requirement – as well as other design features, including the opportunity to use offsets in cap-and-trade and price containment in the LCFS program. The following section provides the rationale for our choices of these sector-specific transportation measures and targets.

For the LCFS, this study considers a 2030 carbon intensity target of a 15% reduction to reflect carbon intensity targets of 15% or 20% below 2010 levels by 2030, which the *First Update to the Climate Change Scoping Plan* discussed.[7] To reflect today's carbon intensity target, we also consider a constant LCFS target of 2% reduction from 2010 levels. In addition, we consider the LCFS design feature related to the price cap on LCFS credits. The ARB established the credit clearance market (CCM) in which regulated parties and credit generators are able to trade LCFS credits. The price of LCFS credits traded through the CCM is capped at $200/MT;[8] however, it is unclear how this mechanism will affect the overall market price for LCFS credits. We therefore consider two boundary cases: no price cap on LCFS credits and a hard cap on LCFS credit prices so they will never exceed $200/MT.

Regarding efforts to reduce petroleum fuel usage, we include a target to achieve Governor Jerry Brown's pillar of a 50% reduction in petroleum usage by 2030. We include this transportation specific policy in some of the scenarios. To be consistent with the ZEV mandate, we impose a requirement that there must be 1.5 million ZEVs on California roads by 2025. Post 2025, no policies exist, though some analysis suggests there could be over 6 million[9] ZEVs by 2030. To

[5] The $N_{ew}$ERA model fully integrates a detailed bottom-up, unit level electricity sector model with a top-down U.S. macroeconomic model.

[6] In this study, we assume that all revenues from the sale of cap-and-trade allowances are recycled back to households in a lump sum manner, which in general is economically more efficient than a policy to expend the revenues on specific projects. Therefore, this analysis most likely understates the cost of California's cap-and-trade program as it is currently being implemented with earmarking of revenues for specific projects.

[7] "First Update to the Climate Change Scoping Plan: Building on the framework Pursuant to AB 32 *The California Global Warming Solutions* Act *of 2006*," May 2014. http://www.arb.ca.gov/cc/scopingplan/2013_update/first_update_climate_change_scoping_plan.pdf

[8] Throughout this paper, ton refers to metric ton of $CO_2$.

[9] Energy+Environmental Economics E3, California Pathways GHG Scenario Results, April 2015.

be conservative, we consider two different minimum requirements for the number of ZEVs on California roadways by 2030: 2.0 million and 4.5 million. Given recent suggestions by the Environmental Justice Advisory Committee to consider eliminating the use of offsets,[10] the scenarios consider a range of offsets from 0% to 8% of an entity's obligation. Table 1A lists this study's six scenarios and highlights the differences in their policy measures, targets, and allowable level of offsets.

**Table 1A: Differing Policies Employed and Level of Offsets Allowed for Scenarios Analyzed**

| | Proposed 50% Reduction of Petroleum Use by 2030 | | LCFS (Improvement in Carbon Intensity from 2010) | | LCFS Price Cap | ZEV Requirement (Millions of ZEVs) | | Offsets Allowed (% Obligation) |
|---|---|---|---|---|---|---|---|---|
| **Scenarios** | **2020** | **2030** | **2020** | **2030** | | **2025** | **2030** | |
| ARB Scoping Plan (SP) | 17% | 50% | 10% | 15% | Yes | 1.5 | 4.5 | 8% |
| LCFS Driven | N/A | N/A | 10% | 15% | No | 1.5 | 2.0 | 8% |
| Market Driven | N/A | N/A | 2% | 2% | No | 1.5 | 2.0 | 8% |
| LCFS Driven Cap | N/A | N/A | 10% | 15% | Yes | 1.5 | 2.0 | 8% |
| ARB SP No Offsets | 17% | 50% | 10% | 15% | Yes | 1.5 | 4.5 | 0% |
| Market Driven No Offsets | N/A | N/A | 2% | 2% | No | 1.5 | 2.0 | 0% |

Note: When no price cap on LCFS credits exists, the LCFS targets are met. The model shows that when there is a cap on LCFS credit prices, the LCFS targets are not met when the cost to comply with them exceeds the $200/MT price cap (the cap currently found in ARB regulation).

The baseline includes the Federal CAFE standard, and the scenarios include an LCFS, ZEV requirement, and an emissions cap to reduce GHG emissions by 40% from 1990 levels by 2030. Therefore, all scenarios include policies that induce a reduction in petroleum use (see Table 1B).

**Table 1B: Common Policies for All Scenarios**

| | GHG Target | | Cap and Trade[11] | Efficiency Standard (Improvement from 2010) | RPS Program Renewables Requirement | |
|---|---|---|---|---|---|---|
| Year: | 2020 | 2030 | | 2030 | 2020 | 2030 |
| Target: | 1990 levels | 40% below 1990 levels | Yes | Double | 33% | 50% |

[10] Environmental Justice Advisory Committee's (EJAC) Draft Initial Recommendations for Discussion Draft Version of 2030 Target Scoping Plan Update Drafted by EJAC at April 4, 2016 Meeting http://www.arb.ca.gov/cc/ejac/meetings/040416/draftinitialrecommendations.pdf

[11] All scenarios impose a cap-and-trade program to ensure that the GHG targets are met. Besides the electric sector, the solution to meet the target does not map to a specific set of technology choices.

All scenarios include a cap-and-trade program that sets California's 2020 emissions target at 1990 levels and then imposes a linearly declining cap from 1990 levels in 2020 to 40% below 1990 levels by 2030. Our model of the cap-and-trade program assumes that all revenues from the sale of allowances are recycled back to households in a lump sum manner, which is economically more efficient than a policy to expend the revenues on specific projects.

All scenarios are run against a baseline that includes a 20% Renewable Procurement Standard (RPS) target and the Federal Corporate Average Fuel Economy (CAFE) standards. The study's baseline does not include California's cap and trade program, the Low Carbon Fuel Standard (LCFS), building efficiency standards, the Zero Emission Vehicle (ZEV) requirement, or the 33% RPS target. By choosing this baseline, the model can account for the full economic impact of California's climate change policies for 2020 and can provide important comparative results for 2030 policies.

A model baseline depends on assumptions about economic activity; such as forecasts about the energy markets and emissions as well as macroeconomic forecasts and anticipated policies. The model's results for a particular scenario are a function of the economic and policy assumptions in the baseline as well as the characteristics of the particular scenario. The most important result is what the model says about the different scenarios. The differences among scenarios provide guidance on the most cost-effective policy options. The results of the scenario comparisons would be nearly the same if the model's baseline assumed the existence of AB 32. Therefore, this study's results are presented as a series of comparisons among scenarios that incorporate different policy choices to achieve a 40% reduction in California's emissions by 2030.

**How does the cost-effectiveness of ARB's 2030 Scoping Plan proposal compare to plans that would include a different mix of emission reduction measures and targets?**

The ARB SP scenario represents the ARB's proposed Scoping Plan for achieving the 2030 emission reduction goal, including a target to achieve a 50% reduction in petroleum use[12] and an LCFS. The LCFS Driven scenario removes the 50% reduction in petroleum use target and instead relies on the LCFS without a price cap to achieve transportation emission reductions. The Market Driven scenario does not include the 50% reduction in petroleum use and freezes the LCFS at current levels. Analyzing these three scenarios illuminates the cost impacts of different transportation specific measures and targets compared to a more economy wide emission reduction strategy (the Market Driven scenario).

[12] To achieve the 50% reduction in petroleum use from 2015 levels by 2030, the model applies the most economically efficient mechanism – a general tax – to petroleum gasoline and diesel used in motor vehicle fuel. By applying an ad valorem tax (e.g., sales tax), the model's cost impacts are a best case compared to applying regulations such as tighter carbon intensity targets or ZEV standards which would lead to greater economic impacts and hence even larger costs on California's economy and households.

Key Results:

- In the ARB SP scenario, the average California household would experience a loss of \$1,200 per year in the near-term and \$3,100 per year in the long-term.[13] In the Market Driven scenario, the average household would experience about half the economic loss of about \$740 per year in 2020 rising to \$1,100 per year in 2030. Thus, achieving the 2020 and 2030 emission reduction targets by relying on the transportation specific policies in ARB's Scoping Plan creates twice the loss to households in the near term and three times the loss to households in the long term.

- California experiences losses in gross state product (GSP), amounting to nearly \$110 billion per year by 2030 for the ARB SP policy option and \$40 billion for the Market Driven policy option.

- The magnitude of the impacts on employment differs significantly for the two options. Job equivalents[14] decline by 570,000 and 1,600,000 for the Market Driven and ARB SP scenarios, respectively, in 2030.[15]

- Inducing a 50% reduction in petroleum use in 2030 would require a charge on transportation fuels of \$700 per metric ton (MT) of $CO_2$ or \$7 per gallon. Lower cap-and-trade allowance prices would only partially offset this high cost compared to those in the Market Driven scenario.

- Avoiding the \$7 per gallon charge arising from the target to reduce petroleum use by 50% and relying only on the LCFS to achieve emission reductions in the transportation sector is not cost-effective. The cost of achieving the 2020 and 2030 carbon intensity targets of 10% and 15%, respectively, under the LCFS, in the absence of a requirement to reduce petroleum usage by 50%, is over \$500/MT by 2020 and over \$900/MT by 2030.

- Requiring a 15% reduction in carbon intensity for transportation fuels rather than the Market Driven scenario causes greater losses to household incomes: \$130 and \$380 in 2020 and 2030, respectively.

[13] Losses in household income are measured relative to today's household income, which is estimated to be \$125,000 based on total California consumption and number of California households.

[14] Total job-equivalents equal the change in labor earnings divided by the average annual income per job. The change in job equivalents does not represent a projection of numbers of workers that may need to change jobs and/or be unemployed, as some or all of the loss in labor earnings could be spread across workers who remain employed.

[15] These losses represent the net change in job equivalents, which include increases in sectors related to the development and production of renewable energy. But these increases are insufficient to offset the decreases in job equivalents from other sectors of California's economy.

**How do different designs and targets for the low carbon fuel standard (LCFS) affect the cost to reduce greenhouse gas emissions from transportation fuels and impact the economy overall?**

The LCFS Driven Cap scenario includes a cap on the price of LCFS credits at $200/MT. This differs from the LCFS Driven scenario, which allows the LCFS credit price to rise to the amount required to achieve the 10% carbon-intensity target for 2020 and a 15% target for 2030. Comparing the LCFS Driven Cap scenario to other scenarios highlights the changes in the carbon intensity of transportation fuels and the impact of the $200 price cap on LCFS credits.

Key Results:

- If a cap is maintained on LCFS credit prices, then 2030 household losses are only $75 above those under the Market Driven scenario. With the cap in place, however, the LCFS achieves only a 5% reduction in carbon intensity in 2020 and it is not until 2028 when the LCFS achieves a 10% reduction in the carbon intensity of transportation fuels.

- The model shows that regulators can either maintain credit prices at $200/MT or meet the statutory 2020 LCFS target (10% reduction in carbon intensity) and the proposed 2030 target (15% reduction), but not both simultaneously. LCFS credit prices that are necessary to achieve the LCFS carbon-intensity targets are more than 2.5 and 4.5 times the $200 capped price in 2020 and 2030, respectively.

**How does including or excluding offsets in the cap-and-trade program affect the cost of reducing emissions?**

Both the ARB SP and Market Driven scenarios allow 8% of an obligated party’s emissions to be satisfied by reductions outside of the cap-and-trade sectors, known as offsets. The last two scenarios, ARB SP No Offsets and Market Driven No Offsets, prohibit entities regulated under cap-and-trade from using any offsets to comply with their obligation.

Key Results:

- Eliminating the opportunity to use offsets creates more demand for the limited number of allowances available in the cap-and-trade program. As a result, allowance prices increase by 80% to 100% from the comparable scenarios that allow offsets.

- Excluding offsets causes 2030 allowance prices to increase by the equivalent of between about $0.60 and $0.85 per gallon of gasoline. The full increase in 2030 gasoline prices caused by disallowing offsets under the ARB Scoping Plan scenario is $1.53/gallon.

- Eliminating offsets results in additional losses of household income of about $300 in 2020 and up to $450 in 2030.

## Conclusion

There are many ways to achieve Governor Brown's 2030 emissions reduction target. Limiting the use of policies that regulate sector-specific emissions, such as the LCFS and a petroleum reduction target for transportation emissions, can reduce the economic impacts of achieving the 2030 target. In particular, adopting a Market Driven approach by reducing the stringency of the LCFS policy, eliminating the petroleum reduction target, and lowering the 2030 ZEV requirement would cut the impacts to households by $2000/yr. in 2030 compared to the ARB 2030 Scoping Plan. Compared to the Market Driven approach, implementing transportation specific measures and targets raises costs to households by one and half to three times in the 2020 to 2030 time period while achieving the same emissions reduction. Offsets provide compliance flexibility without compromising environmental integrity and are necessary to minimize the costs of meeting the emission reduction targets and protecting the California economy.

# I. INTRODUCTION AND BACKGROUND

California's current and proposed climate change policies will affect every part of California's economy, with the most direct impact falling on California's energy and transportation sectors and energy consumption throughout the economy. To estimate the potential future effects of these policies, the California Manufacturers & Technology Association (CMTA) commissioned NERA Economic Consulting (NERA) to conduct a study of the potential economic impacts of California's current and proposed climate policies on the California economy. NERA relied upon publicly available forecasts and price data[16] and NERA's proprietary energy-economic model, $N_{ew}$ERA, to conduct the analysis.

## A. AB 32 – California's Current Climate Policies Through 2020

In 2006, the California state legislature passed and Governor Arnold Schwarzenegger signed, Assembly Bill No. 32 (AB 32 – the "California Global Warming Solution Act of 2006"), which calls for enforceable greenhouse gas emissions limits. These limits decline to a 2020 target of 1990 statewide emission levels. The California Air Resources Board (ARB) spelled out their choices how to achieve the 2020 emission target in the 2008 AB 32 Scoping Plan. Included in this scoping plan is an economy-wide cap-and-trade program and direct measures. Regulation under the cap-and-trade program started in 2013.

The cap-and-trade program is scheduled to run through 2020. From 2015 to 2020, the emissions cap declines by approximately 3% per year so that by 2020, the emissions cap is equal to California's 1990 emissions levels. The emissions cap is divided into annual budgets, each of which specifies the number of allowances created for each year. At the end of each compliance period (roughly every three years), each regulated entity must have acquired and surrendered allowances equal to its level of emissions. The price paid for allowances flows through the economy by increasing the price of fossil fuels directly and affects factors including household income, industrial production, and jobs.

## B. California's Proposed Climate Policies Beyond 2020

Governor Schwarzenegger's original executive order in 2006 called for California to reduce its greenhouse gas emissions (GHG) to 80% below 1990 levels by 2050. AB 32 sets a goal to accomplish this task for a period through 2020.

[16] This study makes use of data from the following public sources: California Public Utilities Commission (CPUC) Long-Term Procurement Plan (LTTP), California Energy Commission's (CEC) Integrated Energy Policy Report (IEPR), the California Independent System Operator (CAISO), assumptions used by ARB, and the Energy Information Administration.

In April 2015, Governor Jerry Brown issued an executive order establishing an interim GHG reduction target of 40% below 1990 levels by 2030 in support of reaching an emissions reduction target of 80% below 1990 levels by 2050.[17]

ARB is in the process of developing an updated Scoping Plan to outline how to achieve the 40% reduction target. Policies such as cap-and-trade are market-based and cover most of the GHGs in the economy. Direct measures cover only emissions from a particular source and more narrowly prescribe how to accomplish the reductions. ARB has a choice as to which policy instruments to emphasize in its Scoping Plan.

Examples of direct measures currently in effect include the low carbon fuel standard (LCFS), which requires a 10% reduction in the carbon intensity of transportation fuels from 2010 levels by 2020. As of 2016, about a 2% reduction has been achieved. Another direct measure regulation is the renewable portfolio standard (RPS), which requires 33% of electric generation come from non-fossil sources, such as wind and solar, by 2020.

In March 2012, Governor Brown issued an executive order directing state government to help accelerate the market for zero-emission vehicles (ZEVs) in California. This executive order established several milestones on a path toward 1.5 million ZEVs in California by the year 2025.[18]

On October 7, 2015, Governor Brown signed SB 350 (DeLeón) to require an increase in the RPS to 50% and a doubling of building energy efficiency by 2030. While not included in SB 350, Governor Brown includes an "up to 50%" reduction in petroleum (gasoline and diesel) use by vehicles as one of his six key climate change strategy "pillars". The ARB included a 50% petroleum reduction goal in the draft 2030 Target Scoping Plan, which is scheduled for ARB approval in the fall of 2016. As part of an effort to reduce petroleum use by 50% by 2030, ARB may choose direct measures such as LCFS in addition to others. In particular, ARB suggested in its *First Update to the Climate Change Scoping Plan,* that it might choose to extend LCFS beyond 2020 and lower its carbon intensity targets to 15% or 20% below 2010 levels by 2030.[19]

[17] Governor Brown's Executive Order B-30-15: https://www.gov.ca.gov/news.php?id=18938

[18] https://www.gov.ca.gov/docs/DRAFT_2015_ZEV_Action_Plan_042415.pdf

[19] "First Update to the Climate Change Scoping Plan: Building on the framework Pursuant to AB 32 *The California Global Warming Solutions Act of 2006*," May 2014. http://www.arb.ca.gov/cc/scopingplan/2013_update/first_update_climate_change_scoping_plan.pdf

# II. MODEL DESCRIPTION AND ASSUMPTIONS

To quantify the economic impacts of policy options for achieving California's 2030 emissions target, NERA employed its $N_{ew}$ERA modeling system, which is an integrated energy and economic model that includes a bottom-up representation of the electricity sector. The model includes all of the unit-level details that are required to evaluate changes in the electric sector, with a U.S. macroeconomic model representing California as a separate region. The model has been designed to assess, on an integrated basis, the effects of major policies on electricity, other energy markets, and the overall economy. For this study, the $N_{ew}$ERA model is designed to simulate ARB policy options and current command and control regimes to evaluate the cost effectiveness of policy options considered in the ARB's 2030 Scoping Plan. The NewERA model is a long-term, fully dynamic model that includes the assumption that households and firms develop optimum decisions over the entire modeling horizon, with perfect information about their options throughout the model horizon (i.e., they have perfect foresight).

The electricity model accounts for over 30 electricity market regions; the US macroeconomic model represents four regions. In particular, the electric sector module includes 38 power pools, six of which are in California. The macro model divides the U.S. into the following four regions: California, the remainder of the Pacific Northwest (excluding California), the Western Electricity Coordinating Council (WECC) (excluding the Pacific Northwest), and the remainder of U.S. (excluding WECC and the Pacific Northwest). The model divides the economies into 13 economic sectors, which includes six broad energy sectors: natural gas, (including CNG/LNG for transportation), coal, crude oil, electricity, refined petroleum products, and biofuels (e.g., conventional ethanol, sugar ethanol, biodiesel) and seven non-energy sectors: agriculture, energy-intensive sectors, manufacturing, services, motor vehicle manufacturing, transportation (non-trucking transportation sectors), and trucking.

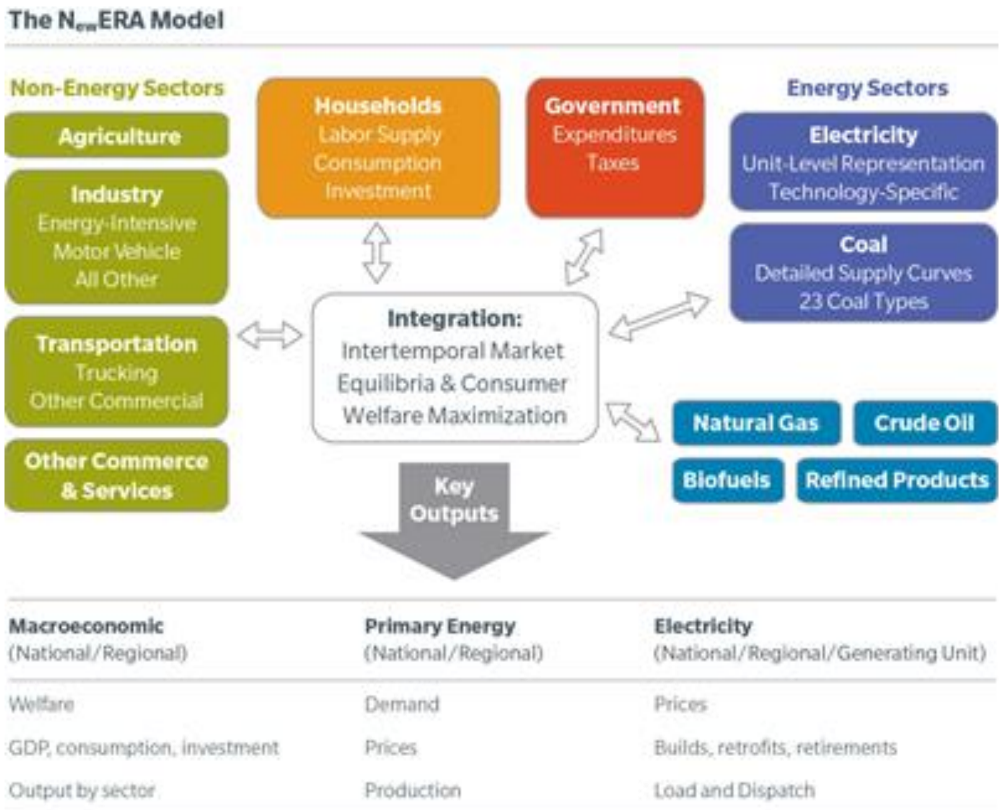
The $N_{ew}$ERA model takes into account only $CO_2$ emissions associated with fossil fuel combustion within these sectors. In general, the model does not account for the emissions of non-$CO_2$ GHGs. The model does account for purchases of offsets if allowed in the scenario and allowances from the allowance price containment reserve (APCR) mechanism that represents about 4% of the total market's allowances in 2020.[20]

The model solves in three-year time steps, in which each year represents a three-year span from one year before to one year after the model year. Specifically, the model solves for the years 2016 to 2037, in which 2016 represents the span of the years 2015 to 2017 to minimize potential terminal effects. This study, however, focuses on and presents results for the 2016 to 2030 time period.

[20] ARB has not proposed a design nor amount of allowances reserved under the APCR for the post-2020 time period.

The figure below provides a high-level overview of the model components, linkages, and key outputs.

**Figure 1: Overview of the Main Components and Outputs of the N$_{ew}$ERA Model**




The N$_{ew}$ERA model is based on a unique set of databases constructed by combining economic data from the IMPLAN 2008 (MIG Inc. 2010) database and energy data from the U.S. Department of Energy's Energy Information Administration's (EIA's) *Annual Energy Outlook 2015* (*AEO 2015*). The IMPLAN 2008 database provides Social Accounting Matrices (SAMs) for all states for the year 2008. These matrices have inter-industry goods and services transaction data; we rebuild the SAM and merge the economic data with energy supply, demand, and prices consistent with *AEO 2015* from EIA. For California, we further adjust this database to include California agencies' data on carbon emissions, energy usage, and prices.

After defining the benchmark year data, we calibrated the model to a baseline forecast, which assumes that AB 32 is not in place. Thus, in the baseline, California has no statewide GHG target, no LCFS policy, and a 20% RPS target for 2020. We measure the impacts of the various GHG reduction scenarios against this calibrated baseline. The EIA's *AEO 2015* Reference forecast is the basis for the baseline forecast for the non-California regions in the model. The baseline forecast for California makes use of the same EIA forecast combined with California-specific data. In particular, the model relies on the California Public Utilities Commission (CPUC) Long-Term Procurement Plan (LTTP) to model future resource needs and California

Energy Commission's (CEC) Integrated Energy Policy Report (IEPR) to model California demand assumptions. The model also relies upon data released by the California Independent System Operator (CAISO) and assumptions used by ARB.

The model assumes no market failures; thus, the costs estimated by the model of achieving the 2030 goal will be an underestimate of the actual costs.[21] The $N_{ew}$ERA model's assumptions about the availability and cost of new technologies to meet the 2030 goal are based on publicly available data, primarily from CEC's IEPR, the ARB's Initial Statement of Reasons LCFS scenario, and the U.S. EIA's AEO.

[21] Common market failures such as reduced uptake of energy efficiency measures due to rental and long-term pay back scenarios, capital constraints of individuals, and illiquidity are excluded.

# III. SCENARIOS FOR EMISSIONS REDUCTIONS BETWEEN 2016 AND 2030

California has options how to meet the Governor's environmental goal of a 40% reduction in emissions from 1990 levels by 2030. The options range from policies that rely heavily on market-based programs, such as economy wide cap-and-trade regimes, to programs that rely heavily on direct measures or sector-specific emissions regulations. To understand the economic trade-offs of these different types of policies, we consider scenarios that range from those that reflect the Governor's target—now reflected in the ARB's Draft 2030 Target Scoping Plan (ARB SP) that include targeted reductions for transportation fuels—to a scenario that relies more heavily on economy-wide regulation to achieve the statewide goal, to which we refer as "Market Driven."

Comparing the ARB SP scenario with the Market Driven scenario allows us to estimate the economic impacts of the basket of transportation sector specific regulations the ARB SP proposes. We also consider a scenario that more closely mirrors regulations currently in place with the addition of a LCFS regulation that calls for a 15% reduction in the carbon intensity of transportation fuels by 2030. We refer to this scenario as "LCFS Driven." Comparing the LCFS Driven scenario to the Market Driven scenario allows us to understand the incremental cost of a 15% LCFS program the ARB is considering in the Scoping Plan process.[22]

These three scenarios are designed to assess different options of policy design for achieving the Governor's 2030 emission reduction target. Specifically, they differ in the direct measures and targets that apply to the transportation sector: a 50% petroleum reduction target, the LCFS regulation, and the ZEV mandate. Table 2 shows the 2020 and 2030 targets for the petroleum reduction policy and LCFS standard for each scenario, as well as the 2025 and 2030 vehicle targets for the ZEV mandate. The ARB SP scenario includes more stringent transportation sector specific policies, which require more reductions to be achieved from the transportation sector, while the Market Driven scenario allows those reductions to be achieved across the entire economy. In order to show the true cost of meeting the LCFS targets, the LCFS Driven scenario does not include a price cap on LCFS credits, whereas the ARB SP assumes a firm price cap of $200/MT for the LCFS credits. This firm cap is intended to serve as a proxy for the cap that the ARB has put in place for LCFS credits traded through the Credit Clearance Market (CCM). The cap in the ARB SP scenario differs from that of the actual LCFS policy in that it places an upper limit on the price of **all** LCFS credits, whereas the cap on credit prices traded through the CCM places no cap on credits traded outside the CCM.[23]

[22] First Update to the Climate Change Scoping Plan: Building on the framework Pursuant to AB 32 *The California Global Warming Solutions Act of 2006,* May 2014.

[23] The 2015 LCFS re-adoption caps the price at which regulated parties and credit generators can exchange credits in the CCM. If LCFS credits had a firm price cap of $200, then it is unclear if the 10% carbon intensity goal by 2020 would be achieved; therefore, we consider an alternative LCFS scenario to address this question. Appendix A provides detail on this analysis.

These three scenarios allow 8% of an obligated party's emissions to be satisfied by reductions outside of the cap-and-trade sectors, known as offsets. To assess the importance of offsets, we consider two additional scenarios, ARB SP No Offsets and Market Driven No Offsets. These scenarios are similar to the ARB SP and Market Driven scenarios, respectively, except they prohibit entities regulated under cap-and-trade from using any offsets to comply with their obligation.

**Table 2: Transportation Sector-Specific Policies and Offset Availability Present in Each Scenario and Their Targets**

| | Proposed 50% Reduction of Petroleum Use by 2030 | | LCFS (Improvement in Carbon Intensity from 2010) | | LCFS Price Cap | ZEV Requirement (Millions of ZEVs) | | Offsets Allowed (% Obligation) |
|---|---|---|---|---|---|---|---|---|
| Scenarios | 2020 | 2030 | 2020 | 2030 | | 2025 | 2030 | |
| ARB Scoping Plan (SP) | 17% | 50% | 10% | 15% | Yes | 1.5 | 4.5 | 8% |
| LCFS Driven | N/A | N/A | 10% | 15% | No | 1.5 | 2.0 | 8% |
| Market Driven | N/A | N/A | 2% | 2% | No | 1.5 | 2.0 | 8% |
| ARB SP No Offsets | 17% | 50% | 10% | 15% | Yes | 1.5 | 4.5 | 0% |
| Market Driven No Offsets | N/A | N/A | 2% | 2% | No | 1.5 | 2.0 | 0% |

To achieve the 50% reduction in petroleum use from 2015 levels by 2030, the model applies the most economically efficient mechanism—a general tax—to petroleum gasoline and diesel used in motor vehicle fuels.[24] The 40% emissions reduction cap, Federal CAFE standard, and LCFS program also induce some petroleum reduction. For the scenarios with the 50% petroleum reduction target, the model includes a petroleum tax that brings about the necessary additional petroleum reduction to achieve the policy's targets. All scenarios assume a 50% RPS target by 2030 and a doubling of energy efficiency in commercial buildings by 2030 as required by SB 350 (see Table 3).

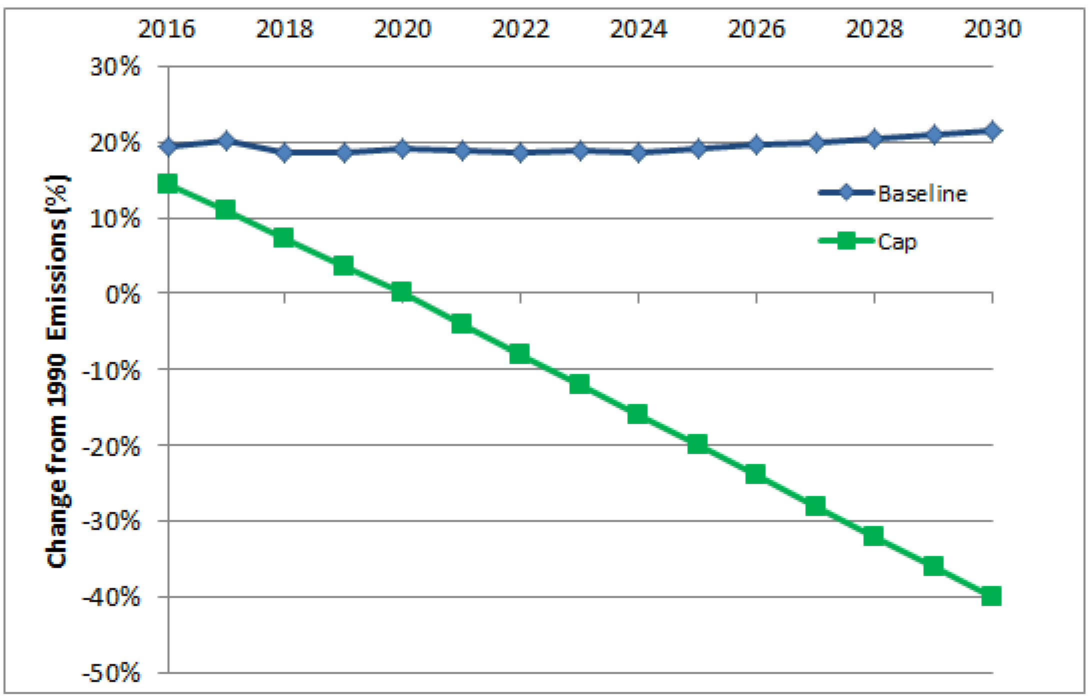
[24] By applying a market based ad valorem tax (e.g., sales tax), the model's cost impacts are a lower-cost case compared to applying direct measures such as tighter carbon intensity targets or ZEV standards. These direct measures would lead to greater economic impacts and hence even larger costs on California's economy and households.

**Table 3: Common Policies for all Scenarios**

| | GHG Target | | Cap and Trade | Efficiency Standard (Improvement from 2010) | RPS Program Renewables Requirement | |
|---|---|---|---|---|---|---|
| Year: | 2020 | 2030 | | 2030 | 2020 | 2030 |
| Target: | 1990 levels | 40% below 1990 levels | Yes | Double | 33% | 50% |

In addition, all scenarios include a cap-and-trade program that sets California's 2020 emissions target at 1990 levels and then imposes a linearly declining cap from 1990 levels in 2020 to 40% below 1990 levels by 2030. Our model of the cap-and-trade program assumes that all revenues from the sale of allowances are recycled back to households in a lump sum manner, which is economically more efficient than a policy to expend the revenues on specific projects. Therefore, our analysis understates the cost of California's cap-and-trade program as it is currently being implemented, with revenues earmarked for specific projects. Figure 2 illustrates the emissions in the baseline and the scenarios as a percentage of California's 1990 emissions. The baseline assumes California has no state-level GHG reduction policy in place except for a 20% RPS.

**Figure 2: Baseline Emissions Forecast and Cap as a Percentage of 1990 Emissions (%)**




All scenarios are designed to achieve the 2030 target of a 40% reduction in GHG emissions. The Market Driven scenario is the most flexible, allowing more reductions to be achieved throughout the entire economy;[25] whereas the ARB SP scenario is the least flexible, directing where emission reductions must be achieved through many sector-specific policies in addition to the flexible cap-and-trade program. The LCFS Driven scenario falls somewhere in between the Market Driven and ARB SP scenarios. Prohibiting the use of offsets for compliance further reduces the flexibility of the ARB SP and Market Driven scenarios, as this action eliminates some cheaper alternative sources of emission reductions.

[25] The Market Driven scenario still has direct measures: RPS, efficiency standard, 2% LCFS, and 1.5 million ZEV requirement by 2025.

# IV. SCENARIO MODELING RESULTS

This section reports the results of the scenarios we analyzed to assess the impacts of California's proposed climate change policies. All scenarios are run against a baseline that includes a 20% Renewable Procurement Standard (RPS) target and the Federal Corporate Average Fuel Economy (CAFE) standards. The study's baseline does not include California's cap and trade program, the Low Carbon Fuel Standard (LCFS), building efficiency standards, the Zero Emission Vehicle (ZEV) requirement, or the 33% RPS target. By choosing this baseline, the model can account for the full economic impact of California's climate change policies for 2020 and can provide important comparative results for 2030 policies.

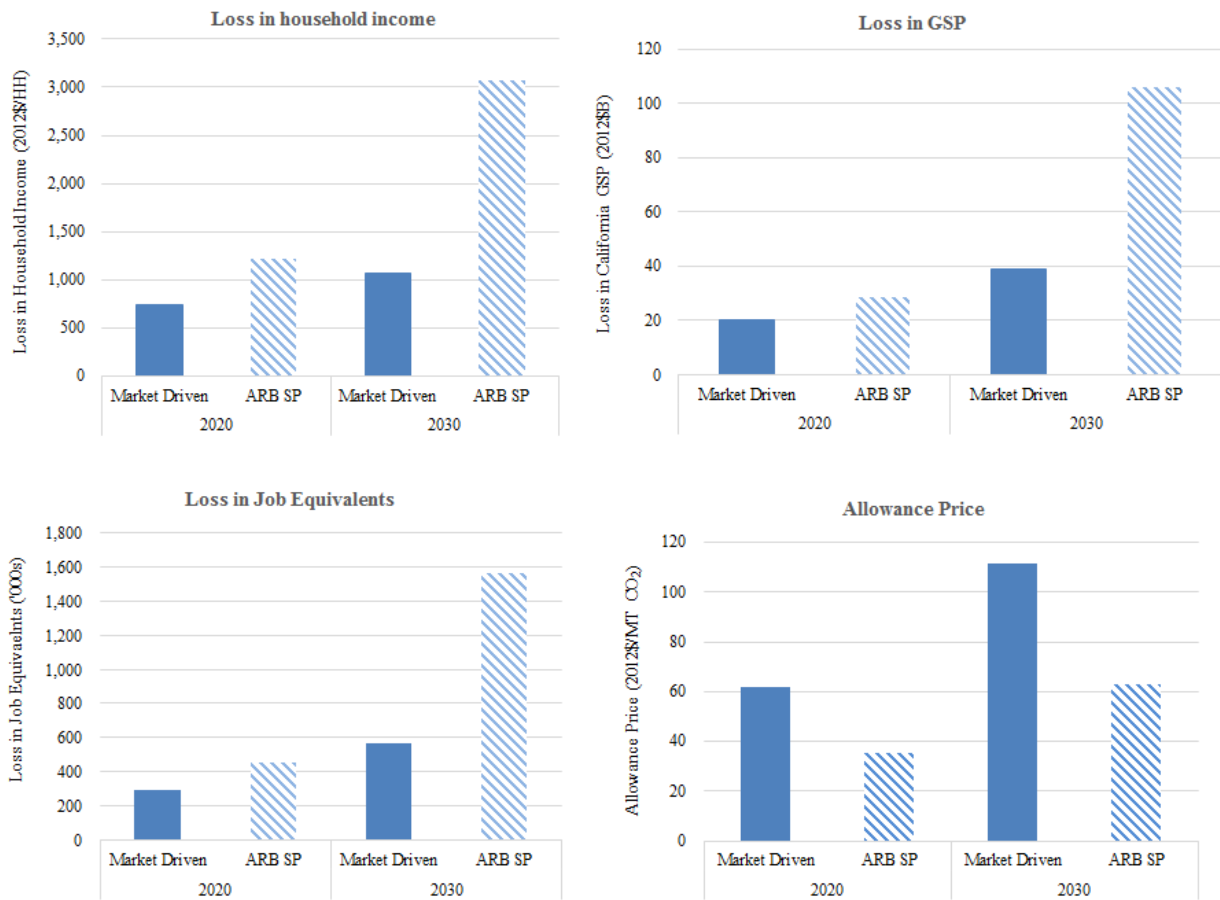
A model baseline depends on assumptions about economic activity, such as forecasts about the evolution of the macro-economy, energy markets, and emissions, and future policies. The model's results for a particular scenario are a function of the economic and policy assumptions in the baseline as well as the characteristics of the particular scenario. The most important result is what the model says about the different scenarios. The differences among scenarios provide guidance on the most cost-effective policy options. The results of the scenario comparisons would be nearly the same if the model's baseline assumed the existence of AB 32. Therefore, this study's results are presented as a series of comparisons among scenarios that incorporate different policy choices to achieve a 40% reduction in California's emissions by 2030.

We first compare the impacts of the ARB SP scenario to the Market Driven scenario. Next, we discuss the impact of the LCFS program by comparing the results from the LCFS Driven scenario with the Market Driven scenario. We conclude with a discussion on the costs of prohibiting offsets in the cap-and-trade program.

## A. Achieving 2030 Goal: ARB Scoping Plan versus a more Market Driven Policy

Figure 3 represents the economic impacts of the ARB SP scenario and the Market Driven scenario. The pattern of higher costs in the ARB SP scenario arises primarily because of the greater stringency and greater number of transportation specific policies associated with the ARB SP scenario. These policies significantly raise the costs to meet the 2030 emissions cap.

**Figure 3: Economic Impacts of Meeting California's 2020 and 2030 Emission Targets – Allowance Price, Loss in Household Income, California's Gross State Product, and Job Equivalents from the Baseline.**




## Overview of findings:

- Governor Brown's 2030 goal can be met and costs can be reduced by limiting the direct transportation specific policies, such as reducing the stringency of the LCFS policy, eliminating the petroleum reduction target, and lowering the 2030 ZEV requirement. Doing so would cut the impacts to households by $2000 in 2030 (ARB SP scenario compared to the Market Driven scenario).

- Under the ARB SP scenario, households would experience almost double the loss in the near term and almost triple the loss in the long term compared to the Market Driven scenario. In the ARB SP scenario, the average household would experience a loss of $1,200 per year in the near term and $3,100 per year in the long term. Alternatively, in the Market Driven scenario, the average household would experience a loss of $740 per year in 2020 rising to $1,070 per year in 2030.

- Changes in California's gross state product (GSP) follow a similar pattern with losses amounting to nearly $110 billion per year by 2030 for the ARB SP policy option and $40 billion for the Market Driven policy option.

- Losses in GSP and household income correspond to a loss of 570,000 to 1,600,000 job equivalents for the Market Driven and ARB SP scenarios, respectively, in 2030.[26] These losses represent the net change in job equivalents, which include jobs increases in sectors related to the development and production of renewable energy; however, these increases are insufficient to offset the decreases in job equivalents from other sectors of California's economy.

- In the ARB SP scenario, targeted command and control transportation specific regulations achieve more of the required emission reductions than cap-and-trade, resulting in higher and less transparent costs for the same GHG reduction. In the Market Driven scenario, over the model horizon, the transportation sector abates emissions by about one-third as much as under the ARB SP scenario.

- While the ARB SP scenario places more pressure on the regulated entities from the sector-specific regulations to make reductions, there are still additional costs, albeit smaller than the Market Driven scenario, from the cap-and-trade program. With the transportation specific policies less abatement is required from other sectors to meet the overall emissions goal and hence reduces demand for cap-and-trade allowances resulting in lower prices for allowances. By 2030, the additional transportation specific policies in ARB SP have the effect of reducing the allowance price from about $110 under the Market Driven scenario to about $60 per metric ton of $CO_2$.

- The reduction in the allowance price in ARB SP comes at the expense of significantly greater costs on the transportation fuels. In 2030, the estimated cost of the additional transportation specific policies is approximately $700/MT of $CO_2$.

**Impacts created by transportation specific policies**

To understand why the transportation specific policies place additional costs on achieving the 2030 emission targets, we first look at how these policies affect the percentage reduction in emission from transportation and rest of the economy. Table 4 reports the percentage change from the baseline for emissions from the transportation sector and the rest of California's economy for the years 2020 and 2030.

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[26] Total job equivalents equal the change in labor earnings divided by the average annual income per job. The change in job equivalents does not represent a projection of numbers of workers that may need to change jobs and/or be unemployed, as some or all of the loss in labor earnings could be spread across workers who remain employed.

**Table 4: Change in Emissions from Baseline for California's Transportation Sector and the Rest of the Economy (percentage change from baseline)**

| Scenario | 2020 | | 2030 | |
|---|---|---|---|---|
| | Transportation | Rest of Economy | Transportation | Rest of Economy |
| ARB SP | -11% | -20% | -38% | -33% |
| Market Driven | -4% | -25% | -14% | -39% |

Overview of findings:

- Because of their prescriptive nature, direct transportation specific policies prevent the state from achieving emission reductions in the least costly manner. In particular, layering on transportation specific policies causes larger emission reductions in transportation at higher costs and smaller reduction in the rest of the economy than in the more flexible Market Driven scenario. In other words, a greater share of the emission reductions occur in the transportation sector and a smaller share in the rest of the economy compared to the Market Driven scenario. The more regulators layer on direct measures and sector specific policies, the more disparate they make the marginal cost of abatement across sectors of the economy.

- The transportation sector-specific policies cause emission reductions in this sector to be larger under the ARB SP scenario than the Market Driven scenario. Furthermore, this difference grows over time. In 2020, emissions in the transportation sector drop by 11% below baseline levels in the ARB SP scenario compared to a 4% drop under the Market Driven scenario – a difference of seven percentage points. By 2030, this gap grows to 24 percentage points as transportation sector emissions decline by 38% from baseline levels in the ARB SP scenario compared to a 14% reduction in the Market Driven scenario.

- The transportation specific policies come much closer to forcing the transportation sector to achieve the same percentage reduction in emissions as the rest of the economy; however, this equalizing of reduction percentages comes at an increased cost to households, reaching $2000 per household by 2030.

- The LCFS credit price and the cost to achieve the 50% petroleum reduction target (i.e., the petroleum tax) reflect the cost of achieving these greater emission reductions in the transportation sector.

    - Under the ARB SP, the 2020 LCFS credit price is about five times that of the cap-and-trade allowance price (see Table 5).

- In 2030 a petroleum tax has the greatest cost of over $700 per metric ton of $CO_2$ reduced (or approximately $7 per gallon of gasoline), over 10 times that of the cap-and-trade allowance price (see Table 5).

**Table 5: Compliance Costs for Cap-and-Trade Allowances, LCFS Credits, and Petroleum Tax (2012$/metric ton of $CO_2$ reduced)**

| Scenario | Cost Metric | 2020 | 2030 |
|---|---|---|---|
| ARB SP | $CO_2$ Allowance Price | $35 | $63 |
| | LCFS Credit Price | 176 | 0[27] |
| | Petroleum Tax | 153 | 726 |
| Market Driven | $CO_2$ Allowance Price | 62 | 111 |

- The cap-and-trade program's allowance price does not reflect the cost of emission reductions accomplished by the transportation specific policies is not reflected in the cap-and-trade program's allowance price. Allowance prices remain low because the emission reductions required in the balance of the economy through cap-and-trade to achieve the statewide cap are lessened because transportation fuels are included under the cap.

- When the scenario includes the transportation-specific policies in addition to the cap-and-trade program, the carbon price is an inaccurate indicator of the overall program cost. Furthermore, as the sector-specific control measures become more stringent and pervasive, carbon prices become more inaccurate as a cost indicator.

## B. Achieving 2030 emissions target: LCFS Driven versus Market Driven scenarios

### How do different implementations of the low carbon fuel standard (LCFS) impact the carbon intensity of transportation fuels and cost to the economy overall?

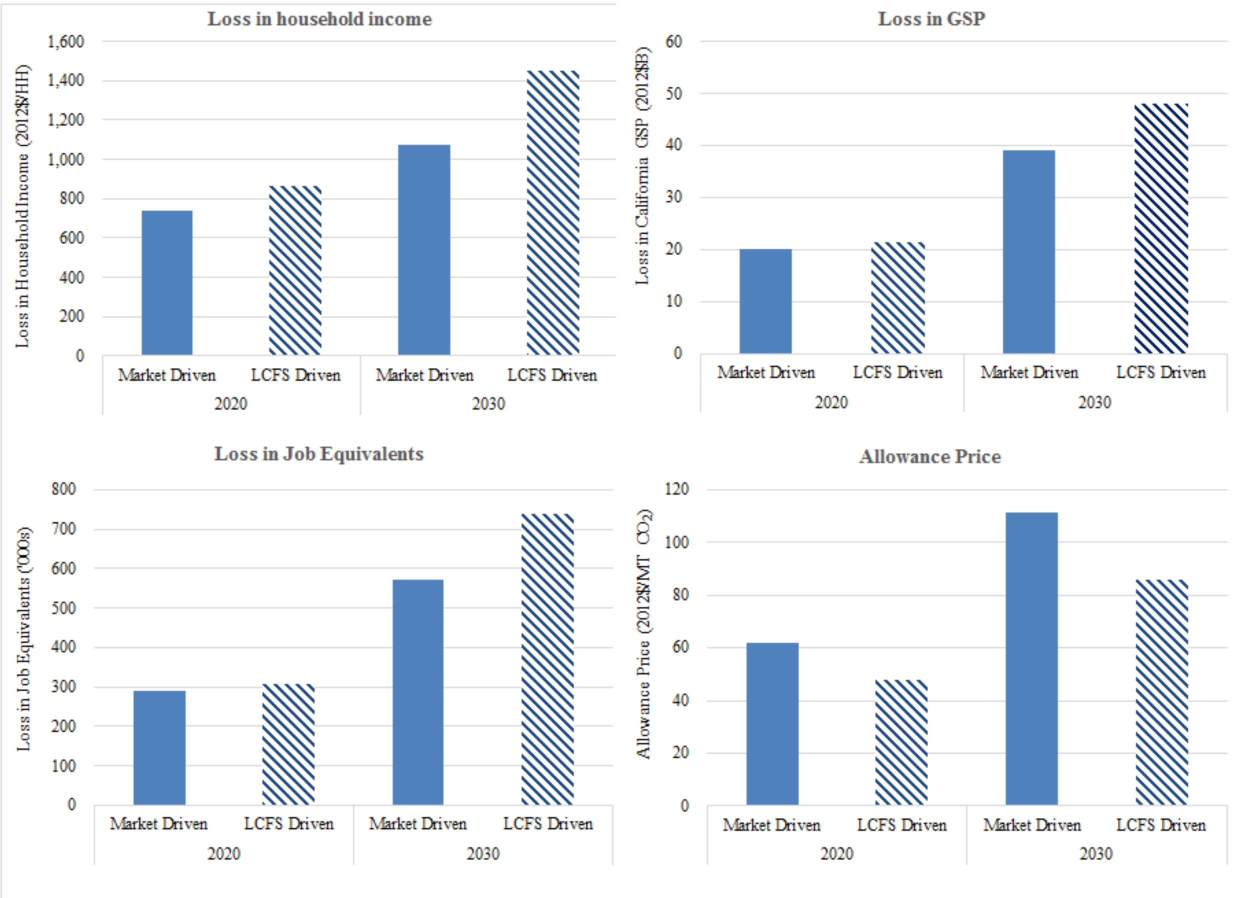
The LCFS Driven scenario achieves the 2030 emissions target by requiring a 15% carbon intensity reduction under the LCFS,[28] which does not include a price cap for credits, along with an economy-wide cap-and-trade policy. This scenario places no price cap on LCFS credits and as such it captures the true incremental cost of an LCFS regulation that achieves the goal of a

[27] The LCFS credit price is zero in 2030 because the petroleum reduction policy forces the transportation sector to be in compliance with the LCFS thus making the LCFS measure superfluous in 2030.

[28] As noted previously, the LCFS policy sets a target of 15% reduction in carbon intensity by 2030 and has no cap on LCFS credit prices. For more information on how a $200/MT cap on LCFS credit prices affects other scenarios, see Appendix A.

15% improvement in carbon intensity in the pool of gasoline and diesel fuel by 2030 (see Figure 4).

**Figure 4: Economic Impacts of Meeting California's 2020 and 2030 Emission Targets with and without LCFS – Allowance Price, Loss in Household Income, California Gross State Product, and Job equivalents from the Baseline**




## Overview of findings:

- Comparing an LCFS Driven policy designed to achieve a 15% reduction in carbon intensity for petroleum products with the Market Driven scenario increases economic impacts on the California economy and its households:
  - Losses in average household income increase by $130 and $380 in 2020 and 2030, respectively.
  - Losses in GSP increase by $1 billion in 2020 and $9 billion dollars in 2030 for a 15% LCFS compared to the Market Driven scenario, which has a 2% LCFS policy over the model horizon.

- By 2030, the additional losses in household income and GSP translate into losses in employment of 170,000 job equivalents.

- Similar to the comparison of the Market Driven scenario and ARB SP scenarios, the cost burden for reducing emissions shifts from the cap-and-trade program to the LCFS. As a result, allowance prices under the LCFS Driven scenario are $14/MT and $25/MT lower than under the Market Driven scenario in 2020 and 2030, respectively; however, costs per household are over 15% and 35% higher in 2020 and 2030, respectively. The cost of the LCFS credits partially reflects the increase in costs, which are over $500/MT in 2020 and increase to over $900/MT by 2030. Therefore, the difference in these scenarios' cap-and-trade allowance prices does not reflect the difference in economic costs of the LCFS Driven scenario and Market Driven scenarios.

- Comparing the Market Driven scenario to the LCFS Driven scenario shows how the implementation of just one additional sector-specific measure can substantially raise costs of achieving the same environmental goals.

## C. Achieving the 2030 goal: Impact of Offsets

By providing greater flexibility, offsets serve an important role in reducing the cost of complying with California's GHG emission targets while also maintaining the same level of environmental efficacy. Changes in the earth's climate brought about by GHG emissions depend on the *global* concentration of GHG. Therefore, total global emissions matter regardless of their geographical location. In other words, planting trees outside of California to sequester a ton of $CO_2$ emissions has the same environmental benefits related to climate change as reducing a ton of emissions from electric generation or vehicle tailpipes.

As part of meeting California's GHG targets, regulators have allowed emitters to meet 8% of their obligation through offsets. This level is currently being debated before the ARB. The ARB has suggested allowing offsets related to jurisdictional Reducing Emissions from Deforestation and Forest Degradation (REDD) Programs because of the importance of deforestation as a contributor to global GHG emissions and California's familiarity with forestry offsets, as well as the many co-benefits such as biodiversity, water management, and soil conservation that would result from mitigating deforestation.[29] On the other side of the debate is the Environmental Justice Advisory Committee, which sees problems with the usage of offsets and has suggested limiting or eliminating their usage.[30]

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[29] ARB presentation "California's Cap-and-trade Program," Feb 2016; http://www.arb.ca.gov/cc/ejac/meetings/040416/cap_trade_overview0229015.pdf

[30] Environmental Justice Advisory Committee's (EJAC) Draft Initial Recommendations for Discussion Draft Version of 2030 Target Scoping Plan Update Drafted by EJAC at April 4, 2016 Meeting http://www.arb.ca.gov/cc/ejac/meetings/040416/draftinitialrecommendations.pdf

Some groups would like to disallow offsets altogether, while others would like to increase the level of allowable offsets above 8%.

To assess the importance of offsets, we modeled two additional scenarios that prohibit usage of offsets: ARB SP No Offsets and Market Driven No Offsets, which differ from the ARB SP and Market Driven scenarios, respectively, in that they disallow offsets. This section compares the results of these two scenarios against the ARB SP and Market Driven scenarios, which allow covered entities to use offsets to meet 8% of their obligation.

Table 6 reports the change loss in 2020 and 2030 household income for the four scenarios: ARB SP, ARB SP No Offsets, Market Driven, and Market Driven No Offsets. Table 7 reports the 2020 and 2030 allowance price for these same four scenarios.

**Table 6: Loss in Household Income from the Baseline with and without Offsets (2012$/HH)**

| Scenario | 2020 | 2030 |
|---|---|---|
| ARB SP | $1,220 | $3,070 |
| ARB SP No Offsets | $1,500 | $3,540 |
| Market Driven | $738 | $1,070 |
| Market Driven No Offsets | $1,040 | $1,390 |

**Table 7: Allowance Price with and without Offsets (2012$/MT $CO_2$)**

| Scenario | 2020 | 2030 |
|---|---|---|
| ARB SP | $35 | $63 |
| ARB SP No Offsets | $72 | $128 |
| Market Driven | $62 | $111 |
| Market Driven No Offsets | $114 | $205 |

**Overview of findings:**

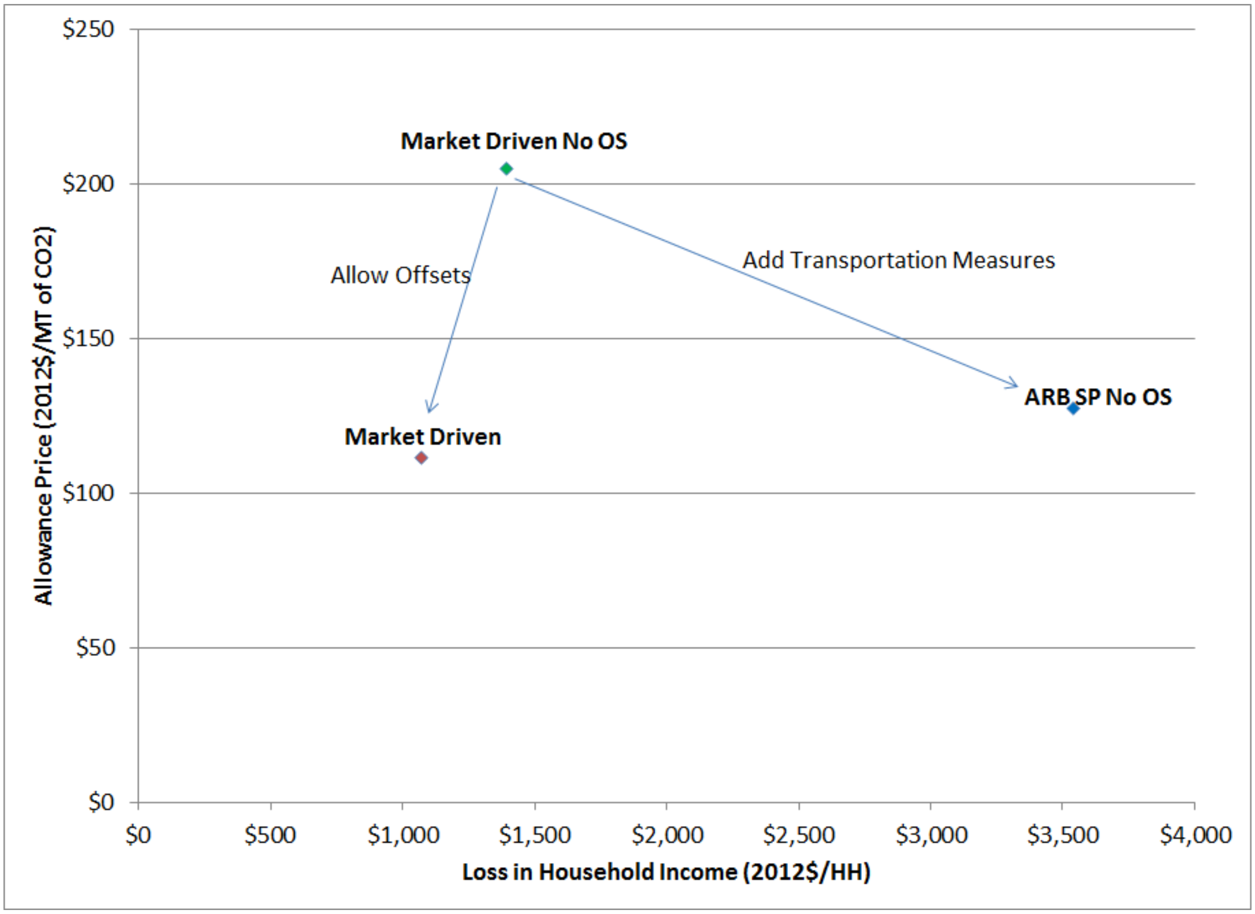
- Requiring additional reductions to come from covered sources, and hence eliminating the flexibility to use offsets, raises allowance prices by 80% to 100%.
- In 2030, the rise in allowance prices is the equivalent of between about $0.60 and $0.85 per gallon of gasoline. Eliminating offsets also increases the petroleum tax needed to reduce petroleum fuel usage in the ARB SP scenario. The increased reliance on the reduction in petroleum fuel usage plus the increase in the allowance price due to lack of offsets equates to an increase in gasoline prices of about $1.50 per gallon.
- Prohibiting the use of offsets increases household losses by about $300 in 2020 and $300 to $450 in 2030.
- Eliminating offsets merely limits flexibility, and hence raises costs, without providing any additional environmental benefits.

**Lowering cap-and-trade allowance prices: Offsets versus transportation specific regulations**

Figure 5 illustrates further the benefits of offsets by showing the effect of offsets and transportation specific policies on the cost of complying with California's emissions targets.

There are two primary ways to lower cap-and-trade allowance prices while still meeting emission reduction targets. One is to impose direct measures that force emission reductions in specific activities that would not have occurred otherwise (e.g., an LCFS to force additional emission reductions in the transportation sector). The second is to increase the scope of the policy by either allowing (or increasing the amount of) offsets or linking the cap-and-trade program with other jurisdictions that have lower abatement costs. Figure 5 illustrates the effect on allowance prices and household income from allowing offsets compared to adding transportation specific policies to the Market Driven No OS scenario.

**Figure 5: Allowance Price vs. Loss in Household Income with and without Offsets and Transportation Specific Policies in 2030**




Adding transportation specific policies lowers the 2030 allowance price from over $200 to about $125 per metric ton of $CO_2$. However, this reduction comes at the large cost of $2,500 per households. Allowing covered entities to use offsets to satisfy 8% of their obligation achieves a similar reduction in allowance prices. Unlike the transportation specific policies, offsets have the additional benefit of lowering costs to households ($300/HH). Therefore, offsets represent an important flexibility mechanism that can be employed to reduce both allowance prices and economic costs. Extrapolating the results of Figure 5, one can infer that increasing the offset limit above 8% would only serve to lessen the costs of reducing California's greenhouse gas emissions.

# V. CONCLUSIONS

There are many ways to achieve Governor Brown's 2030 emissions reduction target. Limiting the use of policies that regulate sector-specific emissions, such as the LCFS and a petroleum reduction target for transportation emissions, can reduce the economic impacts of achieving the 2030 target. In particular, adopting a Market Driven approach by reducing the stringency of the LCFS policy, eliminating the petroleum reduction target, and lowering the 2030 ZEV requirement would cut the impacts to households by $2000/yr. in 2030 compared to the ARB 2030 Scoping Plan. Compared to the Market Driven approach, implementing transportation specific policies raises costs to households by one and half to three times in the 2020 to 2030 time period while achieving the same emissions reduction. Offsets provide compliance flexibility without compromising environmental integrity and are necessary to minimize the costs of meeting the emission reduction targets and protecting the California economy.

# APPENDIX A IMPACT OF CAP ON LCFS CREDIT PRICES

The LCFS currently requires a 10% reduction in carbon-intensity for transportation fuels by 2020. In its 2014 First Scoping Plan Update, ARB said it would "consider extending the LCFS beyond 2020 with more aggressive long-term targets, such as a 15 to 20 percent reduction in average carbon intensity, below 2010 levels, by 2030."[31] Thus, this study chooses to analyze the impact of different implementations of a policy to require a 15% reduction in carbon-intensity by 2030.

As part of the LCFS, the ARB established a Clearance Market in which regulated parties and credit generators can trade LCFS credits. The maximum price for credits acquired, purchased, or transferred via the CCM cannot exceed $200/MT (in 2016 dollars). Whether or not the CCM will actually cap LCFS credit prices is unclear because participants can trade credits outside the CCM and trades on the CCM must be disclosed whereas trades on the open market can be kept confidential.

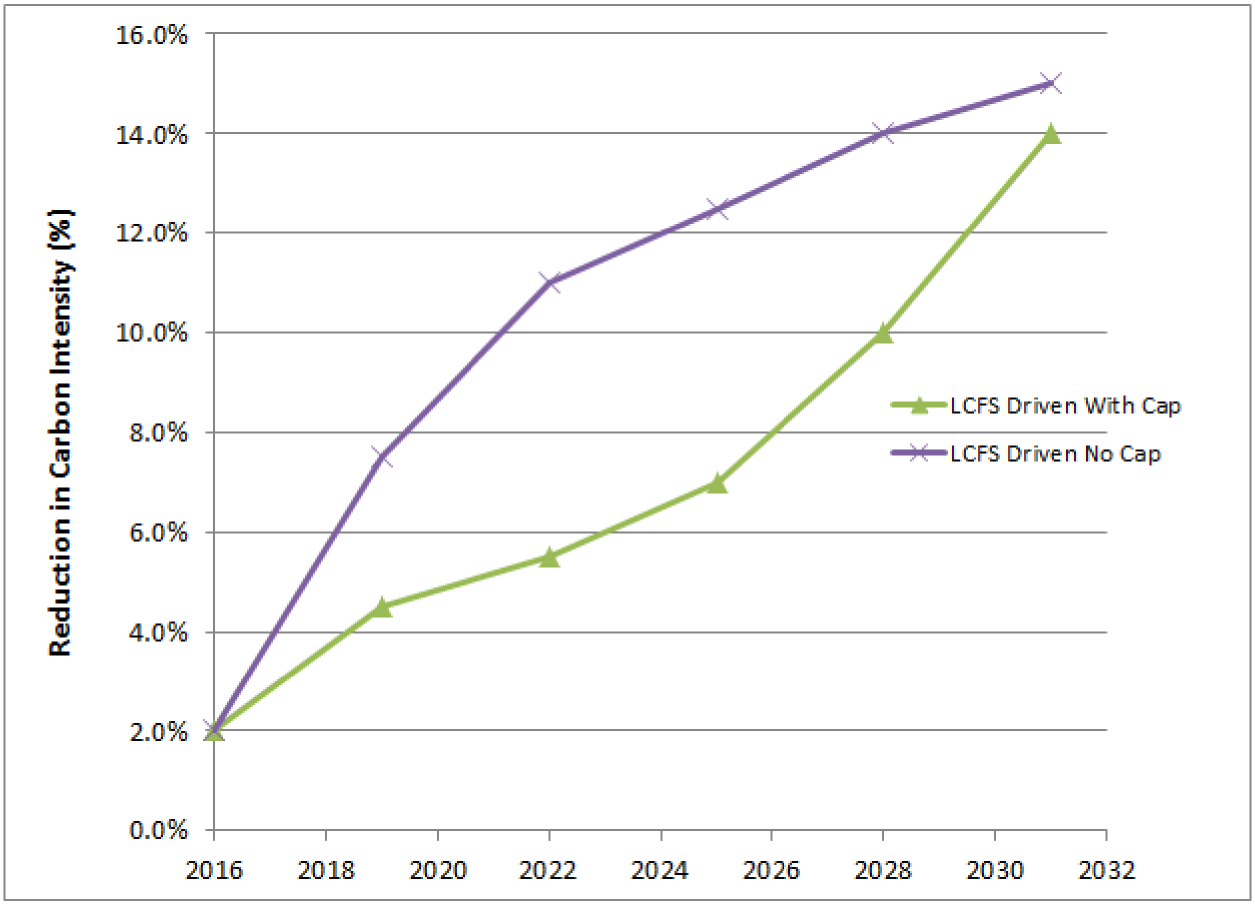
Because of the uncertainty surrounding the efficacy of the CCM at capping LCFS credit prices, we consider two boundary scenarios: LCFS Driven No Cap and LCFS Driven With Cap. The LCFS Driven No Cap scenario is identical to the LCFS Driven scenario described in the body of this report, and assumes no price cap. The LCFS Driven With Cap scenario assumes a hard cap of $200/MT on the price of credits whether or not the credits are traded through the CCM. In this scenario, we assume that the ARB would be the seller of last resort and have an unlimited supply of credits priced at $200/MT; therefore, obligated parties would have the opportunity to buy from the ARB at a price of $200/MT as many credits as they need to meet their obligation. Each credit that the ARB sells at this price reflects a one metric ton of non-compliance with the LCFS targets. Consequently, the price cap on LCFS credits limits compliance costs, but to the extent that obligated parties purchase credits from the ARB rather than the LCFS market, the LCFS target will not be met.

By comparing the price of LCFS credits and reductions in carbon intensity of transportation fuels for these two scenarios, we assess the trade-off between a $200/MT price cap on LCFS credits and compliance with the LCFS targets.

Figure 6 displays the reduction in carbon intensity of transportation fuels for the two scenarios. When the cap is in place, the LCFS program fails to achieve its 2020 statutory target of 10% until 2028 and its 2030 target of 15% until after 2030. For the LCFS Driven With Cap scenario, employing the cap causes the near-term reductions in carbon intensity to be only about half of the statutory targets.

[31] First Update to the Climate Change Scoping Plan: Building on the framework Pursuant to AB 32 *The California Global Warming Solutions Act of 2006*, May 2014.

**Figure 6: Reduction in Carbon Intensity of Transportation Fuels (%)**




The LCFS Driven With Cap scenario caps the LCFS credit price at \$200/MT while under the LCFS Driven No Cap scenario, the credit price rises to over \$900/MT by 2030. In other words, the credit price in 2030 for an LCFS program that meets a 15% reduction by 2030 and the existing statutory targets in every year is \$700/MT more than the price cap. Near-term credit prices under a scenario without a cap depend critically on market participants' expectations of the long-term LCFS target. If participants have full confidence in the statutory targets of 10% and 15% reduction in carbon intensity by 2020 and 2030, respectively, then they will likely over comply and bank credits in the early years, which will cause near-term credit prices to exceed the \$200/MT cap. If, however, participants believe ARB will roll back the statutory targets if credit prices approach the \$200/MT price, then near term prices are likely to remain under the cap and over compliance is likely to be minimal. Given today's LCFS credit prices, the expectations of market participants seem to be more consistent with this latter scenario. Thus, credit prices are likely to rise rapidly if the expectations of a roll back fail to materialize.

In summary, the model finds that either credit prices can be capped at \$200/MT or the LCFS targets (i.e., 10% reduction by 2020 and 15% reduction in carbon intensity by 2030) can be met, but both goals cannot be achieved simultaneously.

# APPENDIX B MODEL DESCRIPTIONS

## A. Electric Sector Model

The electric sector model that is part of the NewERA modeling system is a bottom-up model of the electric and coal sectors. Consistent with the macroeconomic model, the electric sector model is fully dynamic and includes perfect foresight (under the assumption that future conditions are known). Thus, minimizing the present value of costs over the entire time horizon of the model while meeting all specified constraints, including demand, peak demand, emissions limits, transmission limits, RPS regulations, fuel availability and costs, and new build limits are the bases for all decisions within the model. The model setup is intended to mimic (as much as is possible within a model) the approach that electric sector investors use to make decisions. In determining the least-cost method of satisfying all these constraints, the model endogenously decides:

- What investments to undertake (e.g., addition of retrofits, build new capacity, repower unit, add fuel switching capacity, or retire units);
- How to operate each modeled unit (e.g., when and how much to operate units, which fuels to burn) and what is the optimal generation mix; and
- How demand will respond.

The model thus assesses the trade-offs between the amount of demand-side management (DSM) to undertake and the level of electricity usage. Each unit in the model has certain actions that it can undertake. For example, all units can retire, and many can undergo retrofits. Any publicly announced actions, such as planned retirements, planned retrofits (for existing units), or new units under construction can be specified.

Just as with investment decisions, the operation of each unit in a given year depends on the policies in place (e.g., unit-level standards), electricity demand, and operating costs, especially energy prices. The model accounts for all these conditions in deciding when and how much to operate each unit. The model also considers system-wide operational issues such as environmental regulations, limits on the share of generation from intermittent resources, transmission limits, and operational reserve margin requirements in addition to annual reserve margin constraints.

To meet increasing electricity demand and reserve margin requirements over time, the electric sector must build new generating capacity. Future environmental regulations and forecasted energy prices influence which technologies to build and where. For example, if a national RPS policy is to take effect, a portion of new generating capacity will need to come from renewable power. On the other hand, if there is a policy to address emissions, it might elicit a response to retrofit existing fossil-fired units with pollution control technology or enhance existing coal-fired units to burn different types of coals, biomass, or natural gas. All of these policies will also likely affect retirement decisions. The $N_{ew}$ERA electric sector model endogenously captures all of these different types of decisions.

$N_{ew}$ERA divides the U.S. into 40 power pools, six of which are located in California. The model also includes six Canadian electricity regions. $N_{ew}$ERA's detailed representation of California is calibrated to publicly available data and forecasts from various California government agencies. The model relies on the CPUC Long-Term Procurement Plan (LTPP) to model future resource needs; CEC IEPR provided California demand assumptions. The model also relies upon data released by EIA, ARB, and CAISO.

The electric sector model is fully flexible in the model horizon and the years for which it solves. When used in an integrated manner with the macroeconomic model, the model has the same time steps as in the macroeconomic model.

## B. $N_{ew}$ERA Macroeconomic Model

The $N_{ew}$ERA macroeconomic model is a fully dynamic computable general equilibrium model of the United States. The model simulates all economic interactions in the U.S. economy, including those among industry, households, and the government. The macroeconomic and energy forecasts that are used to project the benchmark year going forward are calibrated to EIA's Annual Energy Outlook 2015 (*AEO 2015)* Reference case produced by the EIA, as well as California specific forecasts provided by the CEC and ARB. Because the model is calibrated to an internally consistent energy forecast, the use of the model is particularly well suited to analyze economic and energy policies and environmental regulations.

The $N_{ew}$ERA model's horizon is flexible. For this study, the model was run for different time horizons depending on the scenario being analyzed: either from 2015 to 2025 in one-year time steps or from 2015 to 2036 in three-year increments. The model includes five energy and seven non-energy sectors: energy sectors include crude oil, oil refining, natural gas extraction and distribution, coal, and electricity; the non-energy sectors include agriculture, commercial transportation (excluding trucking), energy intensive sectors, manufacturing, motor vehicle production, services, and trucking.

To represent the consequences of California's LCFS, the model includes several alternative transportation fuels for light duty vehicles and trucks. The model also includes constraints to represent the blend wall and blending limit requirements that exist in the gasoline and diesel markets, respectively. Lastly, the model includes electric vehicles to represent the ZEV mandate and the potential of some electrification of the light duty vehicle sector.

The macroeconomic model incorporates all production sectors and final demands of the economy and is linked through terms of trade. The effects of policies are transmitted throughout the economy as all sectors and agents in the economy respond until the economy reaches equilibrium. The ability of the model to track these effects and substitution possibilities across sectors makes it a unique tool for analyzing policies such as those involving energy and environmental regulations.

The current period policies and market forces inform business investment decisions. The myopic characteristic of the static model determines the optimal consumption and investment based on only the relative price changes in the current period thus agents have no expectation for the future. The alternative approach on savings and investment decisions is to assume the agents in the model have perfect foresight over the horizon, that is, anticipating what will happen in the future can change the consumption-investment decision today. Though both approaches have their limitations, the former approach better reflects market expectations and responses to California's greenhouse mitigation policies given all the uncertainty about future targets, the time lags in defining future targets, and the limited horizon to define future targets.

A single regional representative household represents consumers in the model. The macroeconomic model divides the U.S. into four regions: California, Pacific Northwest, the remainder of the WECC, and the remainder of the U.S. The representative household includes impacts from consumption of goods and services, transportation services, and leisure. The model also represents federal and regional/state level governments and assumes the government collects federal and state taxes to support its expenditures.

We balance the international trade account in the $N_{ew}$ERA model by constraining changes in the current account deficit over the model horizon. The condition is that the net present value of the foreign indebtedness over the model horizon remains at the benchmark year level. Keeping the model horizon at the benchmark year level prevents distortions in economic effects that would result from perpetual increase in borrowing, but does not overly constrain the model by requiring current account balance in each year.

The $N_{ew}$ERA model is based on a unique set of databases constructed by combining economic data from the IMPLAN 2008 (MIG Inc. 2010) database and energy data from EIA's *AEO 2015*. The IMPLAN 2008 database provides SAMs for all states for the year 2008. These matrices have inter-industry goods and services transaction data; we rebuild the SAM and merge the economic data with energy supply, demand, and prices consistent with *AEO 2015* from EIA.

# APPENDIX C MODEL ASSUMPTIONS

## A. Baseline

The baseline forecast for the non-California regions in the model is based on the EIA's *AEO 2015* reference forecast. The baseline forecast for California makes use of the same EIA forecast combined with California specific data. This appendix describes the key third party forecasts that are used to project gross domestic product (GDP) (state or regional level), $CO_2$ emissions, electricity demand, and fossil energy prices for California and the rest of the U.S. These forecasts determine how California and the rest of the U.S.'s economies evolve over time.

### Gross State Product

Overall, economic growth in California is calibrated to a county level economic forecast performed for CalTrans.[32] For the rest of the U.S., the model calibrates economic growth to the *AEO 2015* Reference Case's GDP growth.

### $CO_2$ Emissions

For the model's non-electric sectors, California's baseline emissions are calibrated to the ARB's (Mid Case) Forecast for Updated Scoping Plan (AR4)[33] through 2020. To extrapolate emissions for the post-2020 years, we used two different methodologies. For the non-transportation sectors, we assumed the emissions growth rate post-2020 to be the average growth rate of the ARB's forecast from 2015-2020. For the transportation sector, we made use of the *AEO 2015* Reference case's forecast for the transportation sector, which implies 2030 emissions from light duty vehicles and trucking are about 13% and 6% lower than their 2020 emissions. These forecasts combine to make total 2030 non-electric sector emissions nearly unchanged from 2020 emissions.

Emissions growth for all sectors of the rest of the U.S. is calibrated to the *AEO 2015* Reference case's forecast.

### Electricity Demand

Electricity demand is a key determinant of emissions produced by the electric sector. For California, baseline demand is assumed to follow the IEPR Mid Demand Baseline case[34] from 2016 to 2025. After 2025, the model assumes that electricity demand grows at the forecasted average growth rate from 2020 to 2025. For the rest of the U.S., the model calibrates to the

[32] California County-Level Economic Forecast 2015-2040 prepared for CalTrans by www.californiaforecast.com

[33] *2020 BAU emissions projection version: May 27, 2014 In support of scoping plan update*. http://arb.ca.gov/cc/inventory/data/tables/scoping_plan_forecast_2014-05-22.pdf

[34] California: Form 1.5a, Final California Energy Demand Forecast, 2015-2025, Mid Demand Baseline, Mid AAEE Savings, IEPR, 2015.

EPA's 2015 demand forecast.[35] Table 8 reports the forecasted electricity demand for California and the Rest of the U.S.

**Table 8: Electricity Demand for California and Rest of the U.S. (TWh)**

| Electricity Demand | 2016 | 2020 | 2025 | 2030 |
|---|---|---|---|---|
| **California** | 286 | 292 | 298 | 306 |
| **Rest of U.S.** | 3,620 | 3,930 | 4,050 | 4,180 |

**Energy Prices**

Fossil energy prices in all regions of the model are calibrated to the *AEO 2015*'s Reference case energy price forecasts.

## B. Transportation Sector – Fuels

The cost and availability of alternative transportation fuels determines California's cost to reduce emissions and comply with transportation sector-specific policies. The $N_{ew}$ERA model includes the following alternative transportation fuels: corn ethanol, sugarcane ethanol, cellulosic ethanol, biodiesel, renewable biomass-based diesel (renewable diesel), and natural gas. Natural gas is a blend of conventional natural gas and biogas and is assumed to be in the form of CNG for light duty vehicles and LNG for heavy-duty trucking. All transportation fuels are characterized by their lifecycle emissions factor and cost relative to their petroleum-based counterparts. The transportation fuels lifecycle emissions factor comes from the ARB LCFS Pathways Scenarios.[36] The ARB's May 2015 Proposed 15-Day Changes Scenario reports emissions factors from 2015 to 2025. We assume a constant linear change in the emissions factors from 2025 onward based on the change from 2024 to 2025.

[35] IPM reference for demand

[36] ARB May 2015 Proposed 15-Day Changes Scenario -- Analysis of Compliance Curve With Greet 2.0 CIs and 2014 LRT Data

Table 9 displays the emissions factors used in this analysis.

**Table 9: Lifecycle Emission Factors (g $CO_2$/MJ)**

| Renewable Fuel Type | 2016 | 2020 | 2025 | 2030 |
|---|---|---|---|---|
| Corn Ethanol | 70 | 65 | 60 | 55 |
| Sugarcane Ethanol | 44 | 42 | 40 | 37 |
| Cellulosic Ethanol | 20 | 20 | 20 | 20 |
| Biodiesel | 38 | 38 | 38 | 38 |
| Renewable diesel | 36 | 36 | 36 | 36 |
| CNG/LNG[37] | 51 | 30 | 22 | 21 |

Table 10 reports the price of the liquid alternative fuels relative to their petroleum counterparts on an equivalent energy basis.[38] To the extent possible, these price indices are derived from government sources: EIA's AEO, other EIA documents, and the CEC's IEPR.

**Table 10: Reference Case Fuel Cost Ratios for Blended Gasoline and Diesels (Ratio on a GGE[39] Basis of Biofuel to Conventional Fuel)[40]**

| Renewable Fuel Type | 2016 | 2020 | 2025 | 2030 |
|---|---|---|---|---|
| Corn Ethanol | 1.4 | 1.3 | 1.2 | 1.1 |
| Sugarcane Ethanol | 1.6 | 1.5 | 1.4 | 1.3 |
| Cellulosic Ethanol | 2.2 | 2.2 | 2.0 | 1.7 |
| Biodiesel | 1.7 | 1.6 | 1.5 | 1.4 |
| Renewable diesel | 2.2 | 1.8 | 1.7 | 1.6 |

[37] The CNG/LNG factor represents the average of petroleum based natural gas and biogas according to gas usage in ARB's May 2015 Proposed 15 Day Changes Scenario.

[38] The costs of all ethanols are reported on a gasoline gallon equivalent (GGE) basis.

[39] Gasoline gallon equivalent basis; fuels GGE are adjusted by relative heating value to petroleum gasoline.

[40] All price ratios are national, annual averages over multiple grades of fuel. For gasoline, the grades include regular unleaded, 89 octane unleaded, and premium unleaded.

The following describes how we constructed the cost ratios for the model's biofuels.

Ethanol:

- Corn Ethanol: Ratio of corn ethanol to gasoline is taken from the *AEO 2015* Reference Case, Table A12.
- Sugar Ethanol: Ratio of sugar ethanol prices to gasoline prices taken from CEC's statistics.[41]
- Cellulosic Ethanol: Ratio of cellulosic ethanol prices to gasoline prices based on EIA's cost build up;[42] however, the future cost of cellulosic ethanol is quite uncertain.

Biomass-based diesel:

- Biodiesel: Ratio of soy-based biodiesel to petroleum diesel prices based upon EIA's cost buildup modified for current soybean prices.[43]
- Renewable Diesel: Ratio of renewable diesel to petroleum diesel prices based upon EIA's Cost buildup modified for current feedstock prices.[44]

The ethanol "blend wall" refers to the maximum concentration of ethanol that can be blended in gasoline and used by conventional gasoline-powered motor vehicles. A gasoline blend containing 10% ethanol by volume ("E10") is the only registered ethanol/gasoline fuel approved by EPA and vehicle manufacturers for use in all conventional vehicles today. Flexible fuel vehicles can consume gasolines with much higher blends of ethanol, in particular E85, which contains on average 74% ethanol by volume. Because of costs, performance characteristics, and limited number of vehicles that can consume E85, sales of this fuel are small.

In California, biodiesel is blended into petroleum diesel. The maximum proportion of biodiesel in petroleum diesel is 5% and 10% in the winter and summer, respectively. Therefore, for 2016, we allow maximum blends or blend limits of 7.5% for biodiesel.

In its ARB's May 2015 Proposed 15 Day Changes LCFS Pathways Scenario,[45] the ARB forecasts the blend wall to increase over time as the vehicle fleet turns over and more E85 is sold in the marketplace. The ARB also forecasts renewable diesel to become a bigger share of the diesel pool. Table 11 reflects ARB data from 2015 to 2025 for the blend wall and renewable diesel blend limit. Our model allows for a greater proportion of biodiesel than the ARB has in its Pathways Scenario: The ARB has a blend limit of 5% for biodiesel, whereas our analysis allows biodiesel to be almost 14% of the diesel pool by 2025.

From 2025 to 2030, we assume the same constant increase based on the ARB's average annual increase from 2020 to 2025 in the blend wall and blend limit for renewable diesel to account for

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[41] 2011 Integrated Energy Policy Report, California Energy Commission, February 2012.
[42] Assumptions to *AEO2014*, Table 11.9.
[43] Assumptions to *AEO2014*, Table 11.9.
[44] Assumptions to *AEO2014*, Table 11.9.
[45] ARB's May 2015 Proposed 15-Day Changes Scenario

further fleet turnover, which would allow a greater share of light-duty vehicles and truck to consume higher ethanol blends and higher biomass-based diesel blends, respectively. We also assume that the blend limit for biodiesel can increase to 20% by 2030; however, we have an additional constraint that the maximum share of biomass-based diesel in diesel cannot exceed 35%.

**Table 11: Blend Wall and Blend Limit**

| | 2015 | 2020 | 2025 | 2030 |
|---|---|---|---|---|
| Blend Wall (%) | 10.6% | 11.0% | 11.9% | 13.0% |
| Blend Limit Biodiesel (%) | 7.5% | 7.5% | 13.8% | 20.0% |
| Blend Limit Renewable Diesel (%) | 7.5% | 10.5% | 15.0% | 20.0% |

## C. Electric Sector

The cost of reducing emissions in the electric sector depends critically on the availability and cost of new sources of generation from renewables. The model's assumptions were primarily collected from EIA's *AEO 2015,* documentation for EPA's Integrated Planning Model (IPM), and the CPUC's RPS Calculator.[46] The following tables report the $N_{ew}$ERA assumptions for the rate at which specific technologies can be added to California's grid, the availability of some of these resources, and the cost of new sources of renewable generation.

### 1. Renewable Generation Availability

$N_{ew}$ERA limits the total amount of new renewable capacity that can be added to the grid in California throughout the model horizon. Table 12 displays the limits used in the model by type of unit. These limits are derived from the EPA's IPM version 5.13 Base Case and the CPUC's RPS Calculator.

[46] CPUC RPS Calculator V6.2, see http://www.cpuc.ca.gov/RPS_Calculator/.

**Table 12: Total Renewable New Build Capacity Limits in California (GW)**

| Unit Type | Capacity Limit |
|---|---|
| Biomass | 9.0 |
| Geothermal | 2.0 |
| Landfill Gas | 0.4 |
| Wind | 11 |
| Solar Photovoltaic | No Capacity Limit[47] |
| Solar Tracking | No Capacity Limit |
| Solar Thermal | No Capacity Limit |

For select unit types (biomass, on-shore wind, solar PV and tracking, and geothermal), we set additional constraints on the annual capacity the model can build in California (see Table 13). These limits ensure that the model does not build an unrealistic amount of these resources, and historical capacity builds reported by the CEC's Renewable Energy Statistics and Data informed the limits.[48] $\mathrm{N_{ew}ERA}$ does not limit annual new builds in California for the following unit types: solar thermal and landfill gas.

**Table 13: Annual Renewable New Build Capacity Limits in California (GW)**

| Unit Type | 2016 | 2020 | 2025 | 2030 |
|---|---|---|---|---|
| Biomass | 0.07 | 0.07 | 0.07 | 0.07 |
| Geothermal | 0.06 | 0.12 | 0.12 | 0.12 |
| Solar PV | 2.3 | 2.3 | 2.3 | 2.3 |
| Wind | 1.0 | 1.0 | 1.0 | 1.0 |

### 2. New Renewable Generation Technology

We assumed the following costs and properties for new renewable generation built in California. Cost assumptions for biomass, onshore wind, solar PV, and solar thermal are based on E3's 2014

[47] Solar PV and solar tracking new builds are only constrained by annual capacity limits.

[48] See http://energyalmanac.ca.gov/renewables/.

study prepared for WECC.[49] The remaining cost and property assumptions for offshore wind, landfill gas, and geothermal are derived from the *AEO 2015*'s national numbers. By multiplying the national numbers by a regional cost adjustment, we converted them to California-specific values.

**Table 14: California New Renewable Generation Technology Assumptions[50]**

| Unit Type | Total Overnight Cost in 2016 (2010 $/kW) | Variable O&M (2010$/MWh) | Fixed O&M (2010$/kW/yr) | Heat Rate in 2016 (Btu/kWh) | Capacity Factor (%) |
|---|---|---|---|---|---|
| Biomass | $5,000 | $8.30 | $170 | 13,500 | 85% |
| Geothermal[51] | $5,200 - $6,000 | $0 | $247 - $366 | NA | 87% |
| Landfill Gas | $8,400 | $8.30 | $400 | NA | 90% |
| Wind | $1,600 - $2,200 | $0 | $30 | NA | 18% -36% |
| Solar Thermal | $5,300 | $0 | $62 | NA | 26% |
| Solar Photovoltaic | $1,500 | $0 | $28 | NA | 26% – 31% |
| Solar Tracking | $1,500 | $0 | $28 | NA | 30% - 36% |

### 3. Intermittent Resource Limits

N$_{ew}$ERA limits the share of generation by intermittent resources. The imposition of this system constraint addresses the fact that the grid requires a certain level of firm resources to remain stable. In addition, because of the variability of intermittent resources, the grid requires firm resources that can ramp up and down quickly to maintain a steady flow of power. The limit on the share of intermittent generation is intended to account for these real world phenomena. Because of the large hydro generation resources available to Northern California, the model

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[49] E3. *Capital Cost Review of Power Generation Technologies, Recommendations for WECC's 10- and 20-Year Studies*, March 2014.

[50] Sources for data on Solar PV, Solar Tracking, Solar Th, biomass, natural gas, wind, and geothermal capital costs are from CPUC RPS Calculator. Landfill gas capital costs are from the EIA's *AEO 2015*. For utilization, we relied upon CPUC RPS Calculator V6.2. Wind energy profiles are from IPM Documentation (EPA Base Case v4.10). Capital costs assume production tax credits and investment tax credits are extended through 2030.

[51] Geothermal costs are site specific; therefore, we provide a range of overnight costs and fixed O&M.

places no constraints on the share of intermittent resources, which is consistent with today's operation of the grid in which, for some load pockets, there are times where all generation is coming from intermittent resources. In Southern California, the CPUC has asked the Southern California Investor Owned Utilities to have at least 25% of their generation come from gas-fired resources. Therefore, the NewERA imposes a minimum requirement on gas-fired generation stating that gas-fired generation must supply at least 25% of Southern California's power.

### 4. Capacity for Non-Renewable Sources

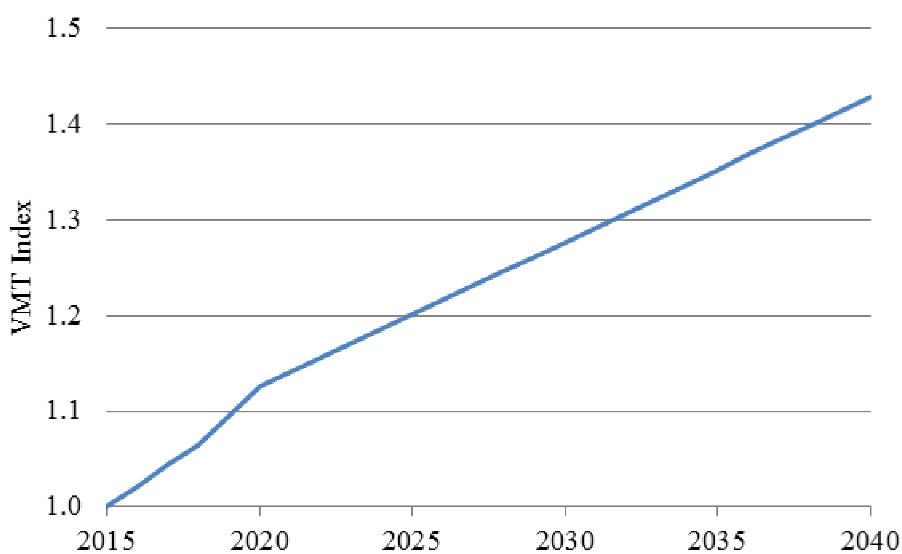
For California, we assume the Diablo Canyon nuclear unit remains on-line throughout the model horizon, but we disallow building any new nuclear or coal-fired generation units in California. To be consistent with the CEC's study on Carbon Capture and Storage (CCS),[52] we assume natural gas-fired CCS can come on-line in 2024. This study projects there is a potential of a one GW/yr build rate over time. In keeping with this study, we adopt this potential as limits in our modeling.

## D. Transportation Sector – Vehicles

### 1. Vehicle Miles Traveled

We assume personal transportation in California will grow at a similar rate to that of the national average; therefore, $N_{ew}$ERA assumes a trajectory for the index of California's vehicle miles traveled (VMT) based on *AEO 2015.*

**Figure 7: California VMT Index Based on *AEO 2015***

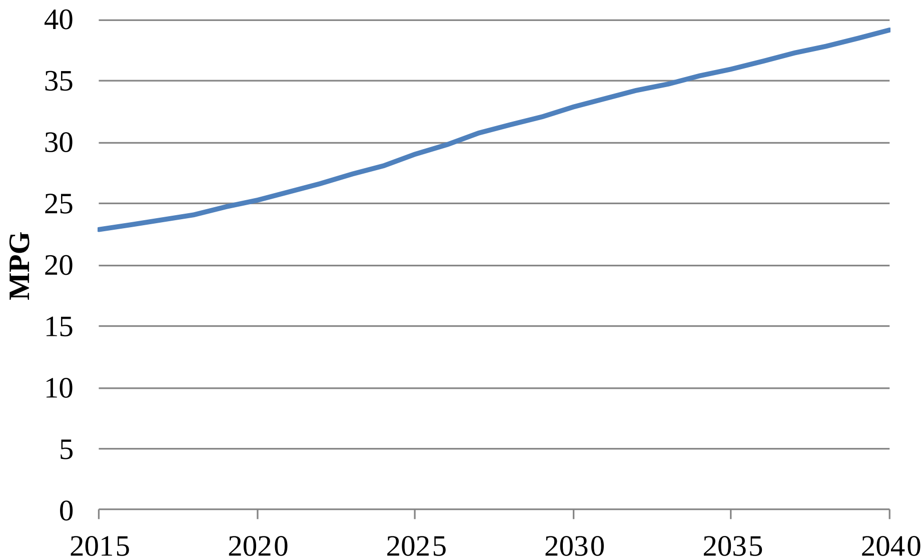



[52] Assessment of Natural Gas Combined Cycle Plants for Carbon Dioxide Capture and Storage in Gas-Dominated Electricity Market, Supporting WESTCARB Initiatives – Consultant Report – Dec 2014 CEC-500-2015-0 (http://www.energy.ca.gov/2015publications/CEC-500-2015-002/CEC-500-2015-002.pdf)

### 2. Efficiency of Conventional Vehicles

We assume vehicle efficiency will improve over time because of Assembly Bill 1493 (by California Assemblywoman Fran Pavley) and the increasing Federal Corporate Average Fuel Standards (CAFE). Using the *AEO 2015* forecast for fleet average fuel economy, $N_{ew}$ERA assumes the following forecast for the fleet average miles per gallon (MPG) in California (see Figure 8).

**Figure 8: California Fleet Average MPG**



### 3. Electric Vehicle Properties

The N$_{ew}$ERA model includes electric vehicles (EVs) whose sales are required to satisfy California's ZEV mandate. For compliance with this mandate, the two key characteristics of EVs are their cost relative to conventional vehicles and their efficiency. The following tables illustrate the assumptions the model employed regarding the cost and performance of EVs. The vehicle cost multiplier is derived from the *AEO 2015* cost multipliers for the 100 mile and 200 mile battery electric vehicles (BEVs) to internal combustion engine vehicles (ICEVs).

**Table 15: Ratio of Cost of the average EV to ICEV**

| | 2016 | 2020 | 2025 | 2030 |
|---|---|---|---|---|
| Vehicle Cost Ratio | 2.05 | 2.03 | 1.77 | 1.65 |

The average efficiency of EVs is also based on the *AEO 2015*'s projected efficiency of 100 mile and 200 mile BEVs.

**Table 16: EV Efficiency (kWh/mile)**

| | 2016 | 2020 | 2025 | 2030 |
|---|---|---|---|---|
| Avg. EV Efficiency | 0.36 | 0.34 | 0.32 | 0.30 |

# APPENDIX D NERA PROJECT TEAM BIOGRAPHIES

**Dr. Paul Bernstein** is a Vice President in NERA's Energy and Environment group in Washington, DC. Dr. Bernstein led NERA's effort helping PG&E's with its 2012 Carbon Metric Analysis. Dr. Bernstein is currently leading NERA's analysis of AB 32 and SB 350 for CMTA. Over the past 20 years, Dr. Bernstein has been involved in the construction, operation, and analysis of economic models involving energy and environmental issues and is the primary developer of NERA's Electric sector ($N_{ew}$ERA Electric), Global Natural Gas Model (GNGM), and NERA's Global Petroleum Model (GPM). Dr. Bernstein has a Ph.D. and an M.A. in Operations Research from Stanford University and a B.A. in Mathematics and Physics from the University of California at San Diego.

**Mr. Scott Bloomberg** is a Vice President in NERA's Energy and Environment group in Washington, DC. He has more than 15 years of experience conducting economic analyses in the energy sector, with a focus on understanding the inter-relationships among fuel markets, environmental regulation, and technological progress. Mr. Bloomberg also manages NERA's $N_{ew}$ERA electricity sector model. Some of his recent project work includes a detailed economic analysis of the projected outcomes of the California electricity markets over the next 30 years and analyses of the proposed and final Clean Power Plan. Mr. Bloomberg has an M.B.A. from the University of Chicago and a B.A. from Northwestern University.

**Dr. Sugandha Tuladhar** is a Vice President in NERA's Energy and Environment group in Washington, DC. Dr. Tuladhar is one of the primary developers of the $N_{ew}$ERA modeling system Dr. Tuladhar's work focuses on economic impact analysis of regional, national, and international energy, environmental, and climate policies and their consequence on the energy industry and other economic sectors. He has led projects and developed energy-economy models to perform economic analysis of major U.S. greenhouse gas reduction policies, including California's AB32, RGGI, President Obama's Climate Action Plan, and most recently regulations of carbon pollution from existing power plants under section 111(d) of the Clean Air Act. Dr. Tuladhar has a Ph.D. in Economics and M.S. in Operations Research and Industrial Engineering from the University of Texas at Austin.

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