California Energy Policy Simulator 3.3.1 Update

Earlier Action Delivers Social and Economic Benefits

CHRIS BUSCH, OLIVIA ASHMOORE, ROBBIE ORVIS, SHELLEY WENZEL

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SUMMARY

California's leadership has been a crucial contributor to global climate progress but needs renewal. Today, the state is not on track to meet its existing climate and clean air goals, which are themselves due for updating based on the latest science.

In 2016, California Senate Bill 32 established a 2030 target requiring 40 percent emissions reductions below 1990 levels, followed by a 2018 executive order calling for carbon neutrality by 2045.[1] Energy Innovation modeling shows California's existing policy commitments would leave statewide emissions nearly 20 percent above its 2030 target.

Hitting state climate and clean energy goals would require the state's emissions to fall below 260 million metric tons (MMT) of carbon dioxide equivalent (CO_2e) to meet the 2030 target and stay on track for the 2045 goal –more than a tripling of California's historical decarbonization rate.

But clarity about the need to accelerate economy-wide decarbonization does not simplify the task. California Energy Policy Simulator (EPS) modeling can identify the path forward by helping policymakers design the most effective emissions reductions portfolios, accounting for economic and social impacts.

ENERGY INNOVATION
POLICY & TECHNOLOGY LLC

www.energyinnovation.org

98 Battery Street, Suite 202
San Francisco, CA 94111
policy@energyinnovation.org

Updated California EPS modeling finds current policy commitments put the state far off course for its next decarbonization milestone, resulting in 2030 emissions of 307 MMT of CO_2e, nearly 50 MMT or 20 percent over the SB 32 target. For context, 1 MMT is equal to the emissions of 215,000 gas-powered vehicles in one year, or 1.1 billion tons of coal burned.[2]

These results indicate the final 2022 Scoping Plan should recalibrate to include identifying early action opportunities for accelerating emission reductions. The Scoping Plan is California's only process dedicated to long-run economy-wide climate planning, and the Draft 2022 Scoping Plan was released in May 2022.[3] The California Air Resources Board (CARB) will take comment on the draft on June 23, 2022 and plans to finalize it no later than the January 2023 Board meeting.[4]

The updated California EPS also shows that accelerating decarbonization in every sector will create billions in benefits for the state. Based on updated California EPS results, Energy Innovation recommends state policymakers focus on five near-term policy priorities:

1. Set course for 100 percent of new cars and light-duty trucks sold to be zero-emission vehicles (ZEVs) by 2030, and for 100 percent of heavy-duty freight trucks sold to be ZEVs by 2035. This policy reduces emissions by 38 MMT of CO_2e/year.[i]
2. Aim for 100 percent electrification of new appliances by 2030, covering new homes and end-of-life replacements in existing homes. This policy reduces emissions by 19 MMT of CO_2e/year.
3. Leverage growing electrification by boosting the clean energy standard to reach around 76 percent renewables and 92 percent zero emissions in 2030. This policy reduces emissions by 11 MMT of CO_2e/year.
4. Use industry performance standards to jump-start industrial decarbonization through fuel switching to electricity and hydrogen, targeting currently available emission reduction potential in food and beverage processing. This policy reduces emissions by 31 MMT of CO_2e/year.
5. Insulate electricity rates from more than $38.9 billion in looming wildfire-related costs to prevent them from becoming a barrier to consumer and business adoption of electric vehicles, appliances, and other energy-consuming capital investments.[5]

The open-source California EPS model is freely downloadable and modifiable. It analyzes policy impacts by comparing total energy use, emissions, cost, and other variables under different scenarios, or combinations of policy settings. The model is accessible via web interface offering more than 100 data visualizations. As an economy-wide model covering more than 50 policy types including carbon pricing, the EPS is well suited to evaluating the effects of a multifaceted climate strategy such as California's.

This report documents an update of the California EPS to platform 3.3.1, following Energy Innovation's initial release in 2020.[6] The updated California EPS develops three policy scenarios:

- The BAU Scenario captures the effect of settled policies, defined as policies with established implementation pathways and statutory authority.
- The Committed Policies Scenario adds executive orders or specific proposals not yet fully backed by established in law or regulation, such as the Advanced Clean Cars II proposal under consideration.

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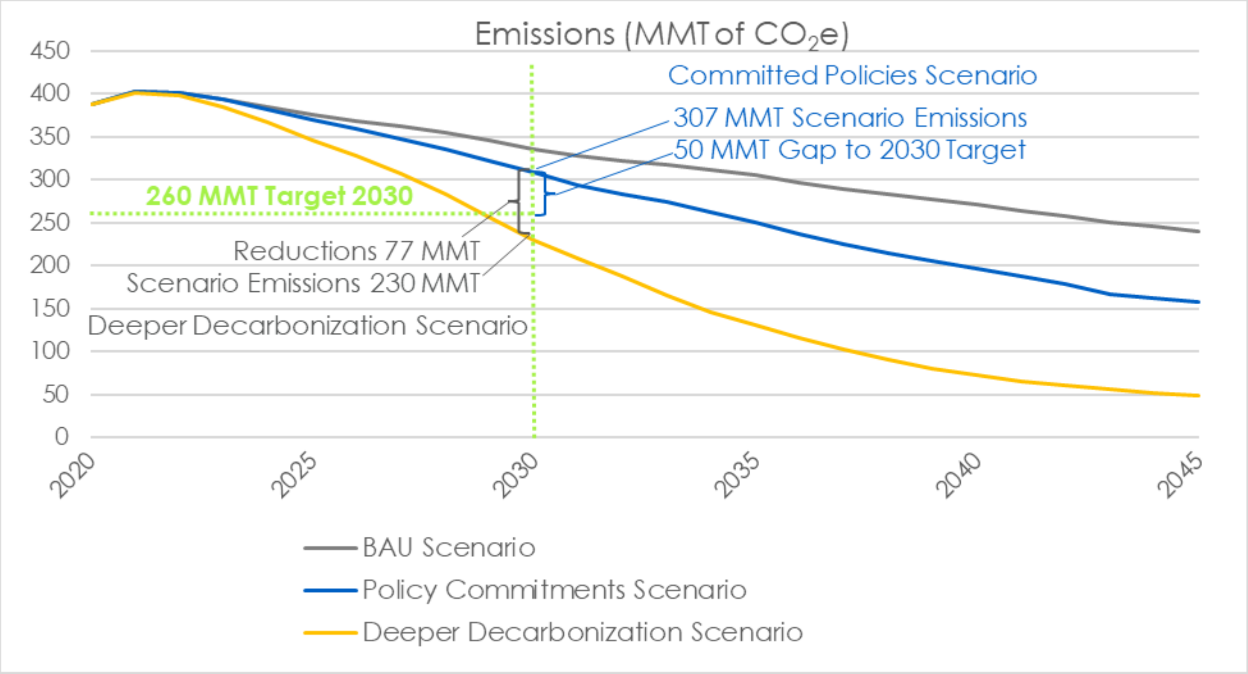
[i] These and other emissions effects reflect average annual emissions reductions as calculated for the 2050 abatement cost curve.

- The Deeper Decarbonization Scenario accelerates emissions reductions significantly below the existing 2030 target while delivering public health and economic benefits.

Figure 1 graphs these scenarios and labels the current compliance gap, referring to the nearly 50 MMT of CO_2e difference between the SB 32 target and 2030 emissions of 307 MMT of CO_2e under the Committed Policies Scenario.[ii] The Deeper Decarbonization Scenario deploys electrification of energy demand and ramp up the power sector's clean energy standard, along with complementary policies and investments to improve grid reliability, driving an additional 78 MMT of CO_2e emissions reductions, lowering emissions to 230 MMT of CO_2e in 2030.

Figure 1. The Deeper Decarbonization Scenario accelerates emissions reductions to get the state back on track



Turning to the top policies in the Deeper Decarbonization Scenario, results indicate cost savings over the 2050 time horizon for three of the four top policies, a result observable in Table 1. The table presents two metrics, boiling down decarbonization impact effectiveness, measured as average annual emissions reductions and cost effectiveness, represented by the net present value (NPV) of changes to spending caused by the Deeper Decarbonization Scenario. A negative cost results, i.e., with a value less than zero, indicates adding the policy causes lower expenditures.

[ii] Though the 2030 target is often referred to as 260 MMT of CO_2e, the 2030 target can be more precisely calculated as 258.6 MMT of CO_2e.

Table 1. Top policies in Deeper Decarbonization Scenario[iii]

	Annual average abatement potential MMT of CO_2e	Cost effectiveness $s per tonne (2050 NPV)
EV Sales Standard	38.3	-$527
Electrification + Hydrogen	30.8	$280
Building Component Electrification	19.3	-$29
Clean Energy Standard	11	-$42

Figure 2 graphs economic benefits, changes in direct cost, and household spending effects from implementing the Deeper Decarbonization Scenario. Figure 3 covers GDP effects in detail, then combined with monetized public health and climate benefits. Figure 4 breaks down job creation by sector and by change in direct, indirect, and induced jobs. Finally, Figure 5 shows lives saved—i.e., avoided premature death because of improved air quality—in total and by percentage of premature deaths avoided by racial group.

Figure 2's left panel shows that direct cost savings amount to tens of billions, due to savings on energy because of investment in more energy-efficient capital. Figure 2's right panel illuminates benefits for consumers, estimated to save $1,540 per household in 2030, reaching savings of $2,426 per household in 2035. Household affordability benefits are especially likely to resonate in the current economy, with war causing fossil fuel prices to spike.

Figure 3 shows early GDP gains of billions, growing to $28 billion in 2030, outpaced in later years by the monetized value of social benefits, the sum of health and climate benefits, which grows steadily to $60 billion in 2050.

Figure 4 breaks down job creation, which rises to 170,000 in 2030, peaking at 196,000 jobs created in 2036. The left panel provides visibility into job changes by sector and the right panel by direct, indirect, and induced employment effects.

Figure 5 shows annual lives saved (or more technically, avoided premature deaths), and the percentage reduction in incidence of premature death by racial group. The California EPS estimates a range of health effects, also quantifying avoided hospitalization and fewer asthma attacks, for example, finding the Deeper Decarbonization Scenario would prevent 26,000 asthma attacks in 2030 and 80,000 asthma attacks in 2044.

[iii] Comparing system emissions and costs under the Deeper Decarbonization Scenario and the BAU Scenario as calculated automatically for the 2050 Abatement Cost Curve in the EPS's web app results.

Figure 2. Economic benefits attributable to the Deeper Decarbonization Scenario

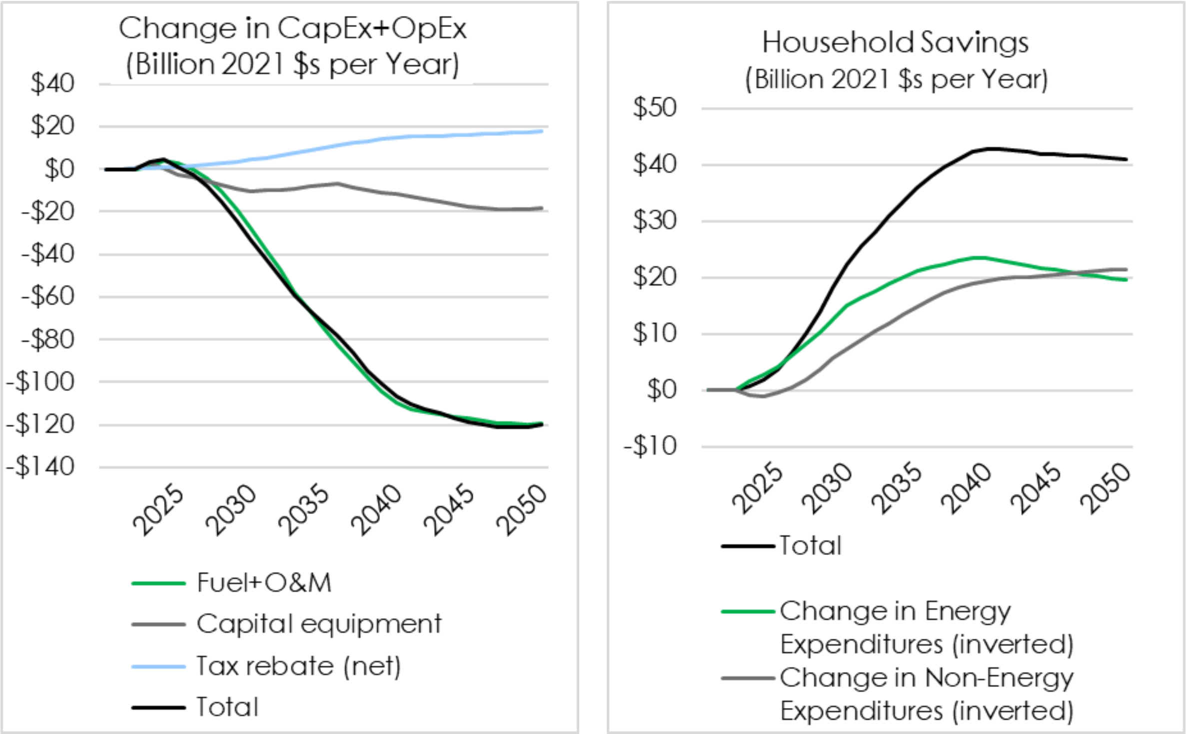


Figure 3. Macroeconomic and monetized social benefits attributable to the Deeper Decarbonization Scenario

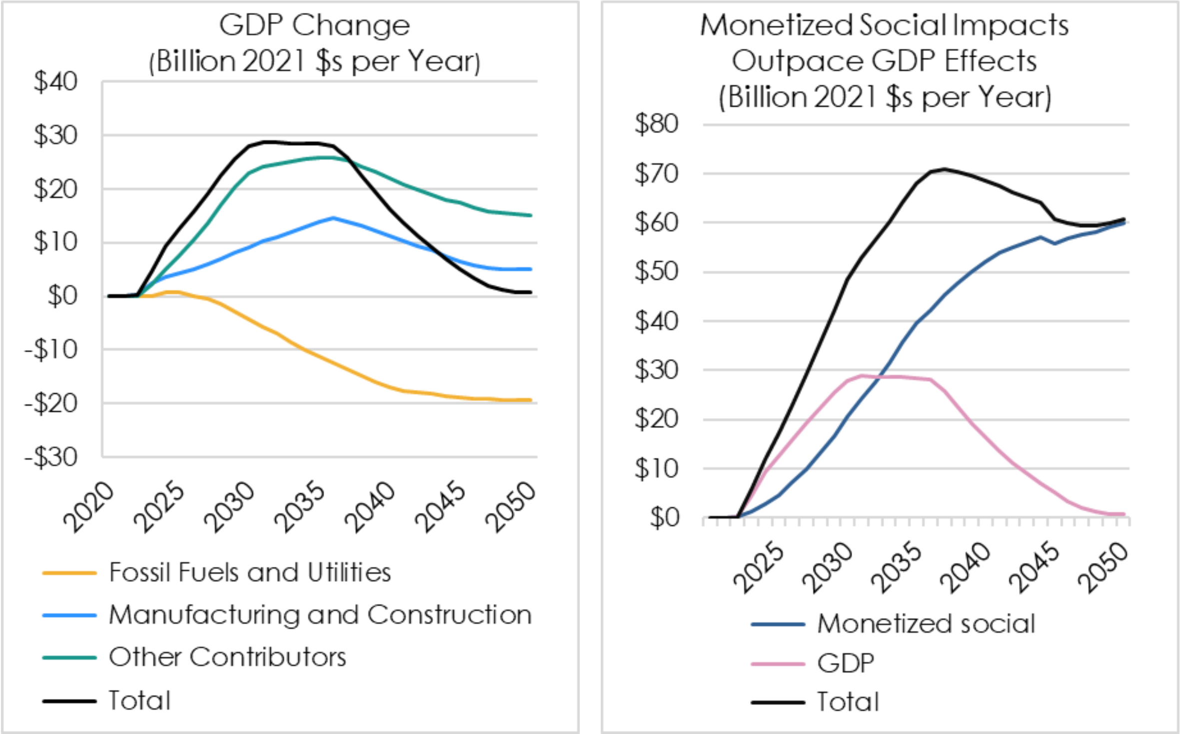


Figure 4. Job creation attributable to the Deeper Decarbonization Scenario

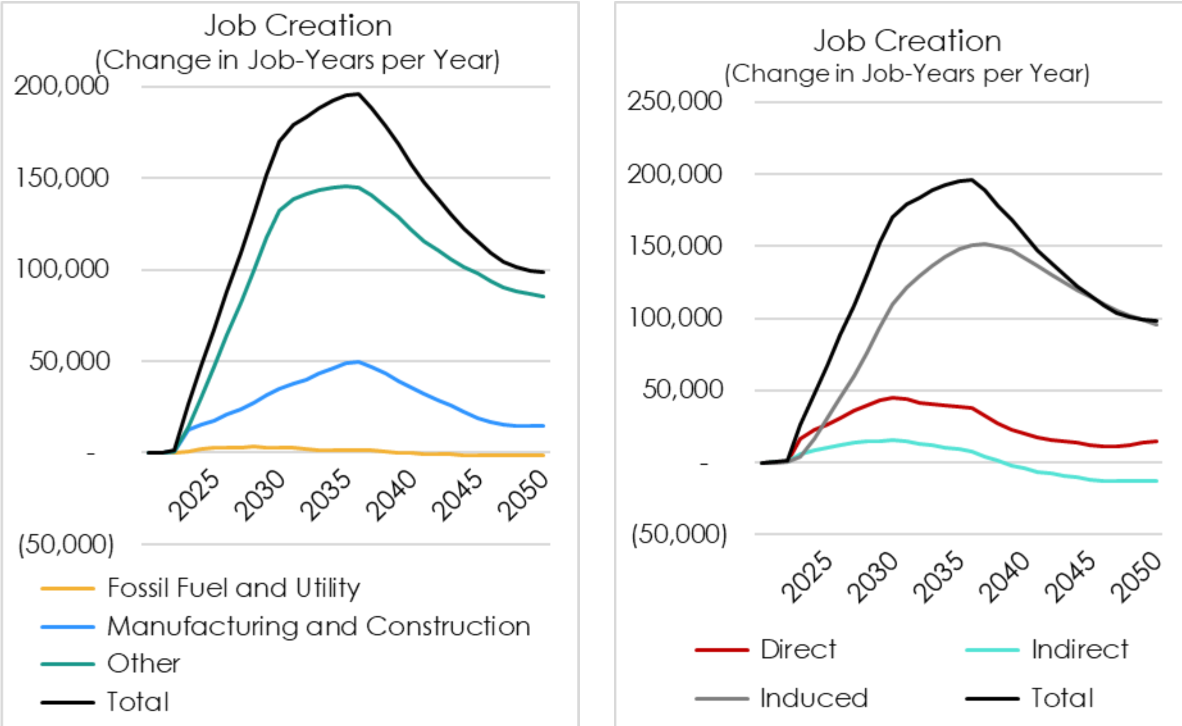
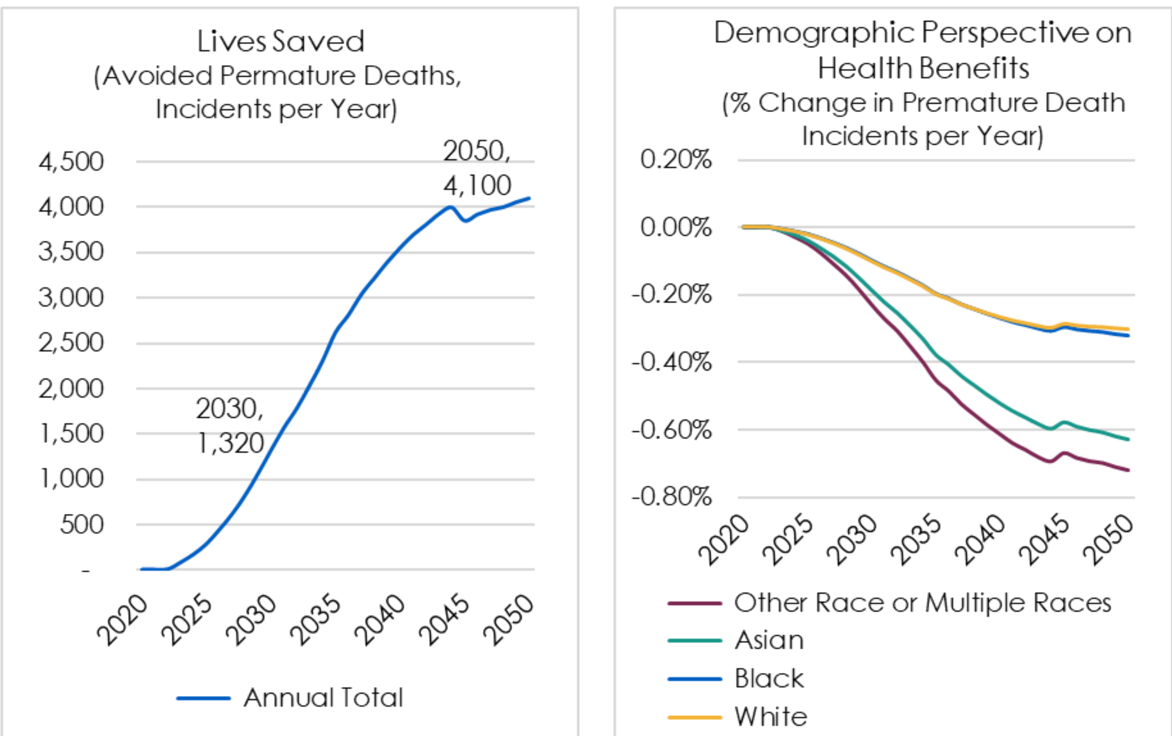


Figure 5. Health benefits attributable to the Deeper Decarbonization Scenario

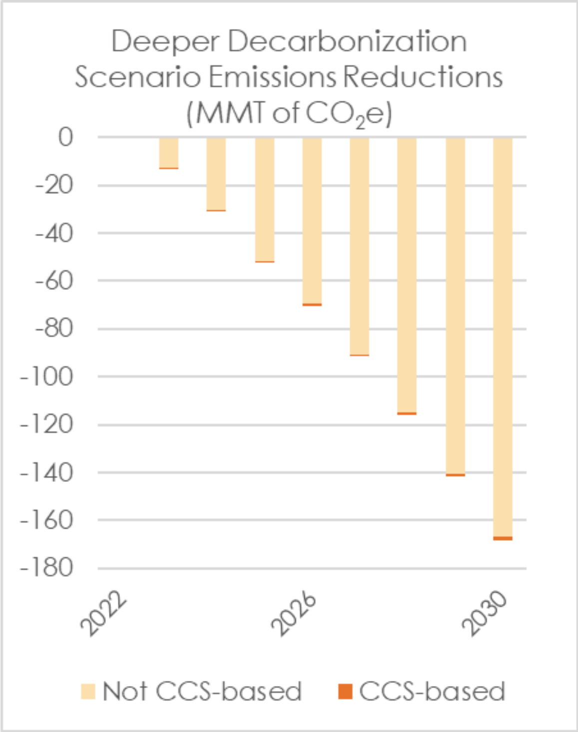


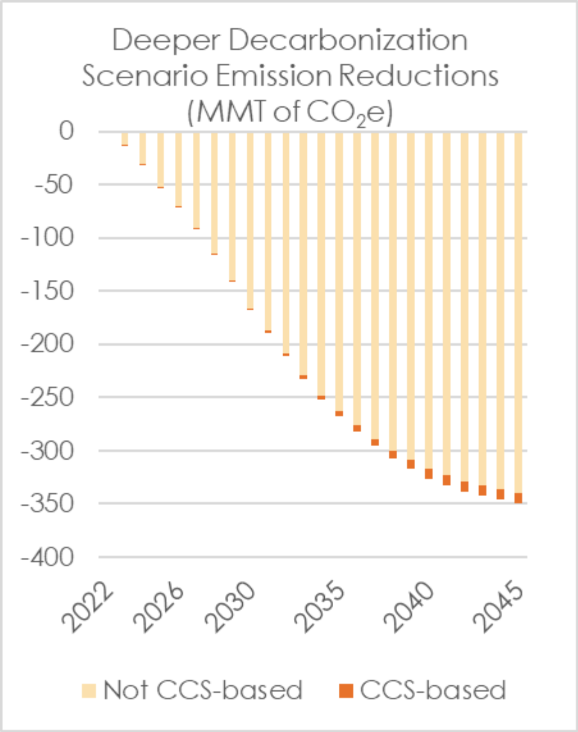
The Draft 2022 Scoping Plan emphasizes the importance of carbon dioxide removal (CDR), particularly mechanical technologies—carbon capture and sequestration (CCS) and direct air capture, unproven technologies.

California EPS results demonstrate the opportunity to rebalance California's climate strategy toward earlier action with currently available solutions, and less reliance on unproven technology like CDR. Results indicate accelerating cost-effective and proven strategies such as electrification and renewable energy deliver a suite of economic benefits.

The proposed Scoping Plan Scenario includes 83 MMT in CDR reductions in 2045, almost entirely by direct air capture. This compares to 10 MMT of CCS by 2045 in the Deeper Decarbonization Scenario, which does not feature direct air capture. Figure 6 graphs emissions reductions over time in the Deeper Decarbonization and proposed Scoping Plan scenarios, with and without CDR, compared to 2022 emissions levels. Figure 7 directly compares total annual CDR in the Deeper Decarbonization Scenario vs. the proposed Scoping Plan Scenario developed as the foundation of the Draft 2022 Scoping Plan.

Figure 6. Comparing CDR-based and other emissions reductions in DD and SP Scenarios





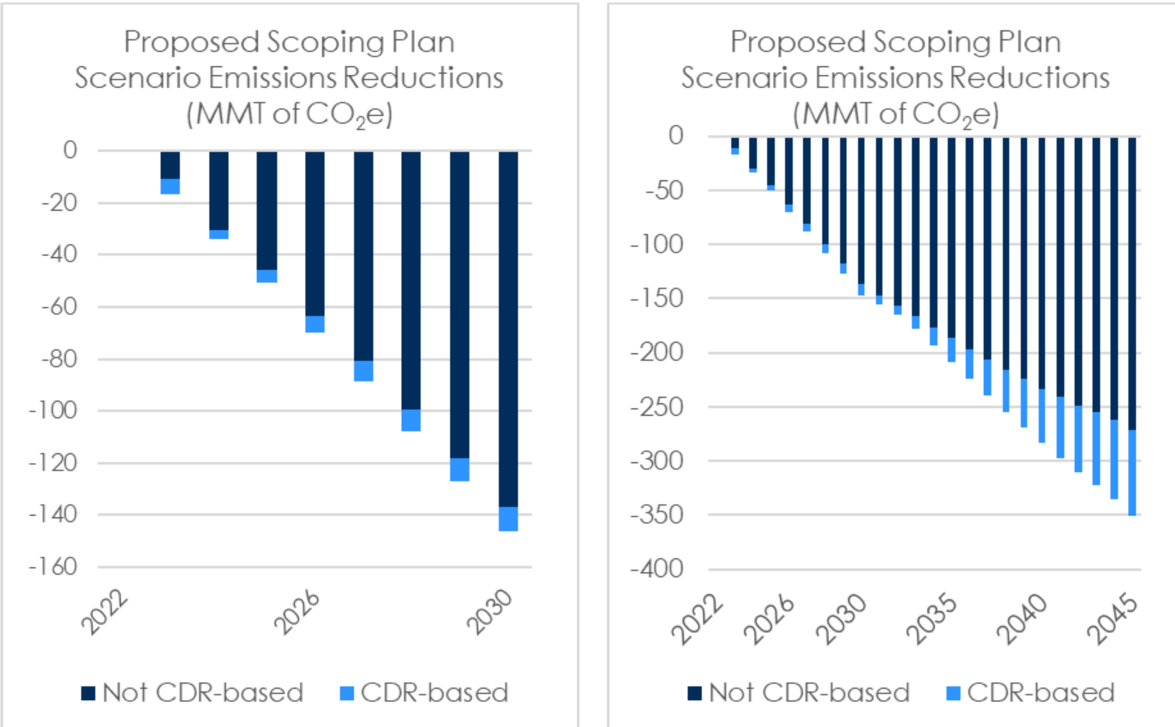
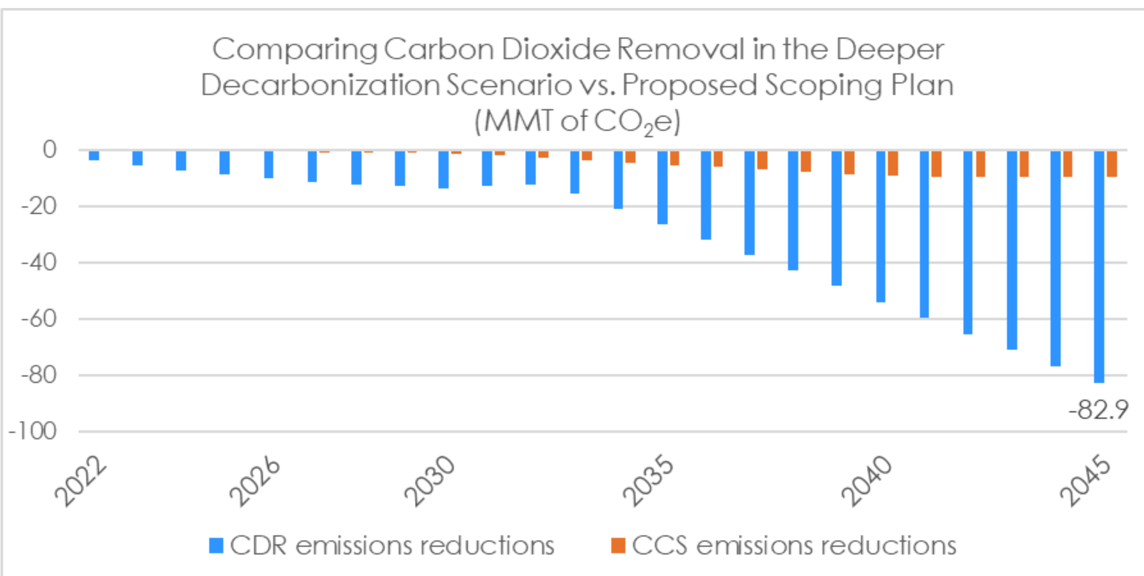


Figure 7. CDR-based emissions reductions in Deeper Decarbonization vs. Proposed Scoping Plan Scenario



Deeper Decarbonization Scenario results indicate California is leaving existing beneficial decarbonization opportunities unleveraged. Phasing out fossil fuels and replacing them with affordable clean energy will build a stronger state economy. Ambitious policies will spur innovation and entrepreneurialism for the clean technologies increasingly in demand worldwide. California residents will benefit from cleaner air and improved health. Several likely co-benefits are beyond the scope of this research, such as improved urban mobility and higher quality of life in cities. The Deeper Decarbonization Scenario path will also reduce California's exposure to volatile world oil markets. Though the cause of shocks vary, current prices are a reminder that the petroleum market is a global and predictably volatile market.[7] And this path will benefit international climate efforts, to which California offers both technological innovation and policy inspiration. We hope the updated California EPS model will be of service to policymakers and all people engaged in the challenging work of shepherding the state's climate strategy.

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INTRODUCTION

California is a national and global climate policy leader, but the state is not on track to meet its 2030 or 2045 goals for climate or clean air. And the latest science shows California must strengthen its targets to align with global climate efforts. Energy Innovation recently updated the California EPS to help state policymakers accelerate its greenhouse gas (GHG) emissions reductions. The California EPS is a tool for helping policymakers identify the most effective, equitable, and efficient climate policies. This report documents the update of the California EPS to platform 3.3.1 and presents results and recommendations informed by updated modeling.

In 2016, California SB 32 established a 2030 target requiring 40 percent emissions reductions below 1990 levels, followed by a 2018 executive order calling for carbon neutrality by 2045.[8] To hit the next target eight years hence, emissions must fall below 260 MMT of CO_2e, requiring more than a tripling of the historical decarbonization rate. For context, 1 MMT is equal to the emissions of 215,000 gas-powered vehicles in one year, or 1.1 billion tons of coal burned.[9]

The 2022 Scoping Plan is an opportunity to identify the best near-term steps for accelerating emissions reductions, and California EPS results identify end-use electrification, along with renewable and clean energy deployment as priorities. Faster decarbonization can also pay off with valuable social and economic co-benefits. The California EPS Deeper Decarbonization Scenario meets and surpasses California's 2030 target and puts the state on track for carbon neutrality by 2045, all without leaning on unproven technology. This accelerated early action generates both social and economic benefits, the former estimated to reach $60 billion in monetized climate and health benefits (2021 $s) far outweighing macroeconomic impacts. GDP changes are larger in earlier years, peaking near $29 billion in 2031.

MOTIVATION

The urgency of reducing GHG emissions is the underlying motivation for this research. John Holdren, President Obama's top science advisor, sums up the current situation this way: "Everything we worried about is happening, and it's all happening at the high end of projections, even faster than the previous most pessimistic estimates."[10] International efforts are coalescing around limiting global warming to 1.5 degrees Celsius or lower, a level that scientists say is within reach and necessary to avoid catastrophic risks.

As an advanced economy known for its technological prowess and innovative climate policy, California must succeed in accelerating its emissions reductions pace. In 2006, California's Assembly Bill 32 set the Western Hemisphere's first economy-wide cap, bringing emissions to 1990 levels by 2020—431 MMT of CO_2e. This provided momentum for international efforts when there was little appetite for climate policies in Washington, D.C. If the world loses one of its decarbonization stalwarts, reducing GHG emissions enough to preserve a safe climate—which is already a stretch—becomes even more challenging.

Another motivation for this work was the need to contribute insights into potentially advantageous early actions for the 2022 Scoping Plan. The Scoping Plan is the state's only process dedicated to long-run, economy-wide climate planning. CARB released a Draft 2022 Scoping Plan in May, with plans to finalize it by the end of 2022 or perhaps at the January 2023 Board meeting.[11]

CARB has made reaching carbon neutrality the central theme guiding development of the 2022 Scoping Plan, which could be the last meaningful chance to recalibrate California's strategy for reaching its 2030 target. The inaugural Scoping Plan developed early action priorities, including the accelerated implementation of the Low Carbon Fuel Standard opportunities.[12] The 2022 Scoping Plan should once again include early action recommendations, and this research provides insights into the most impactful policies.

A renewed search for early action can ensure no existing opportunities go unleveraged. The moment when businesses acquire new capital equipment, or consumers buy new cars or furnaces, is a crucial time for policy because these machines last ten years or more. Forcing machines into early retirement is much more difficult and expensive than ensuring clean investments in the first place.[13] New sales standards take advantage of natural capital stock turnover so that investments align with climate goals. Without robust sales standards, continued investments in fossil fueled equipment will compound future energy and economic system inertia.

RECOMMENDATIONS

Based on new modeling results, Energy Innovation recommends five near-term policy actions:

1. Set course for 100 percent of new cars and light-duty trucks sold to be ZEVs by 2030, and for 100 percent of heavy-duty freight trucks sold to be ZEVs by 2035. This reduces emissions by 38 MMT of CO_2e/year.[iv]
2. Aim for 100 percent electrification of new appliances by 2030, covering new homes and end-of-life replacements in existing homes. This reduces emissions by 19 MMT of CO_2e/year.
3. Leverage growing electrification by boosting the clean energy standard to reach around 76 percent renewables and 92 percent zero emissions in 2030. This reduces emissions by 11 MMT of CO_2e/year.
4. Use industry performance standards to jump-start industrial decarbonization through industrial fuel switching to electricity and hydrogen, targeting currently available emissions reduction potential in food and beverage processing. This reduces emissions by 31 MMT of CO_2e/year.
5. Insulate electricity rates from more than $38.9 billion in looming wildfire-related costs to prevent them from becoming a barrier to consumer and business adoption of electric vehicles, appliances, and other energy-using capital investments.[14]

Updated California EPS results add to the growing evidence supporting the importance of electrification—switching energy demand from oil and natural gas to electricity. California-specific, U.S.-focused, and international studies have previously identified electrification as the most important current decarbonization opportunity considering emissions reduction potential and cost.[15] Today, Russia's war against Ukraine reminds us how electrification policies reduce exposure to volatile global oil markets. The war has caused crude oil prices to skyrocket in world markets, in turn raising prices for gasoline and diesel fuels.

1. **Set course for 100 percent of new cars and light trucks sold to be ZEVs by 2030, and for 100 percent of heavy-duty freight trucks sold to be ZEVs by 2035.** This reduces emissions by 38 MMT of CO_2e/year.

[iv] These and other emissions effects reflect average annual emissions reductions as calculated for the 2050 abatement cost curve.

California EPS modeling finds this policy creates the strongest combination of emissions reduction and cost savings potential, saving $527 per tonne in the 2050 abatement cost curve. This recommendation is more broadly informed by California's successes, strong consumer demand trends, and growing global national commitments to accelerate the ZEV transition. Growing economic upsides and health benefits add up to a cost-effective opportunity for faster progress. To fully leverage the EV transition's potential, the state should aim for all new car sales to be ZEVs by 2030 instead of the current 2035 timeline.

2. **Aim for 100 percent electrification of new appliances by 2030, covering new homes and end-of-life replacements in existing homes.** This reduces emissions by 19 MMT of CO_2e/year.

The California EPS finds that 100 percent building electrification by 2030 delivers the third-largest emissions reductions based on average annual abatement through 2050. Building electrification adds some initial costs, but pays off overtime, providing monetary savings based on net present value through 2050. To be meaningful, a building electrification policy should cover equipment sales in both new homes and retrofits (new appliances to replace worn out ones in existing homes). By way of comparison, the Scoping Plan Scenario models 80 percent electrification by 2030, growing to 100 percent by 2035 for residential buildings and 2045 for commercial buildings.

3. **Leverage growing electrification by boosting the clean energy standard to reach around 76 percent renewables and 92 percent zero emissions in 2030.**[v] This reduces emissions by 11 MMT of CO_2e/year.

As a result of system dynamics captured by the California EPS, updated model results show that even modest increases in the clean energy standards deliver supercharged emissions reductions because of growing use of electricity use from economy-wide electrification. In other words, the California EPS captures positive interactions between the effects of electrification and clean energy standard policies.

The EPS finds increasing the clean energy standard adds costs when considering effects through 2030 but creates net savings through 2050. This is because solar and wind have no fuel input costs, so their lifetime costs are front loaded. This cost structure biases upward the NPV by 2030 metric by failing to fully account for future fuel savings. As a result, the clean energy standard is one of the more expensive policies through 2030, costing several hundred dollars per tonne of CO_2e avoided, but it overall lowers energy system spending—generates net cost savings—considering NPV to 2050.

Note that the abatement cost curve value for the clean energy standard includes costs associated with flexibility investments needed for grid reliability including battery storage, demand response, and transmission and grid upgrades.

4. **Use industry performance standards to jump-start industrial decarbonization, targeting currently available emissions reduction potential in food and beverage processing.** Industrial fuel switching to electricity and hydrogen reduces emissions by 31 MMT of CO_2e/year.

This recommendation is informed by the success in 2021 of SB 598, which established a cement intensity standard and suggests such industry-specific policies could be a template for other industry climate policies. Additional policy signals are needed in industry, given the accumulation of surplus carbon allowance permits under the state's cap-and-trade program and growing appreciation of the unavoidable

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[v] For comparison to current policy debates, legislation under consideration, Assembly Bill 1020, proposes to add interim clean energy targets for the state, calling for renewable energy resources and zero-carbon resources to supply at least 90% of all retail sales of electricity by 2035, increasing to 95 percent by 2040.

weakening effect of free allocation on the carbon price signal, as discussed in this report's Carbon Pricing section.

Recent public investments also indicate a policy window of opportunity. The state's 2021-2022 budget dedicated $210 million to industrial decarbonization, of which $85 million was directed to help food producers transition to sustainable power, including electrification.

Food and beverage production is a major industrial consumer of natural gas in California—the third largest behind oil and gas extraction and petroleum refining, according to California Pathways data.[16] Because food and beverage plants have less extreme heat requirements than most other industries, their natural gas is likely replaceable with existing technology, as discussed in an industrial decarbonization opportunity case study below.[17]

5. **Insulate electricity rates from more than $38.9 billion in looming wildfire-related costs to prevent them from becoming a barrier to consumer and business adoption of electric vehicles, appliances, and other energy-using capital investments.**[18]

Policymakers should protect electricity's affordability because it is a decarbonization linchpin. It would be a tragic irony if climate change impacts themselves undercut the cost effectiveness of the single most important decarbonization fuel (electricity). Instead of using ratepayer funds to cover wildfire damages and investments to protect the electricity grid and ensure future reliability, the state should use other monies, whether from the general fund, carbon allowance auction revenue, or other sources. Doing so will preserve policy effectiveness, equity, and overall affordability.

California EPS results confirm that electric vehicles (EVs) are cheaper than internal combustion engines on an ownership cost basis and are approaching purchase price parity. If wildfire damages feed into electricity rates unchecked, these costs will overwhelm all other factors, depressing consumer incentives. Researchers at the University of California, Berkeley's Energy Institute at Haas have been at the forefront of anticipating growing wildfire costs, urging action to lower electricity prices.[19]

METHODOLOGY

The California EPS is a free, open-source, peer-reviewed model that allows users to estimate climate and energy policy impacts on emissions, the economy, and public health using publicly available data. EPS models have been developed for more than a dozen countries and several subnational regions, including eight U.S. states in addition to California. EPS models now cover 56 percent of global GHG emissions. The California EPS is one of many state-level EPS models that Energy Innovation and RMI are developing. Online documentation explains key EPS data sources, assumptions, and calculation methodologies.

This report summarizes results and recommendations following an update of the California model to EPS platform 3.3.1. The first version of the California EPS was released in January 2020, running on EPS platform 1.4.3. The updated model expands the policy analytical capacity and user-friendly data visualizations offered in the web app. This report focuses on emissions covered under the state's inventory, including energy-related emissions as well as fugitive and process emissions. The EPS also includes land use, land-use change, and forestry-related emissions and policies.

The model's cost metrics track spending on fuels, capital, and other operational and maintenance costs, as well as effects on government ledgers, revenues, and incentive spending. Since the first version of the model, the EPS has added input-output modeling that captures macroeconomic ripples following the direct policy impacts.[20] The EPS also analyzes local air pollutants and public health impacts, using the EPA's BenMAP-CE, which is an open-source computer program that calculates the number and economic value of air pollution-related deaths and illnesses.[21]

As with any policy analytical tool, the EPS carries uncertainties, including the precise impacts of a given policy. Additionally, policies included in the EPS rely on new and developing technologies, particularly in the industrial sector. For example, industry has yet to deploy green hydrogen and carbon capture, utilization, and storage at scale. EPS's open-source character allows anyone interested to explore the effects of different input data, helping to mitigate some of these uncertainties.

The California EPS is uniquely well suited to Scoping Plan analysis, but it is not a substitute for more granular analytical approaches. For example, in electricity, the California Public Utilities Commission's long-term procurement and planning process evaluates electricity system reliability over a 10-year planning horizon. In transportation, CARB develops Standardized Regulatory Impact Assessments to support adoption of all major policies.

DATA

Like the energy and economic models used for the 2022 Scoping Plan analysis, the California EPS requires substantial input data given its economy-wide coverage and technological detail. Table 2 lists key data sources for model inputs, starting with important cross-cutting references and then covering individual sectors. The model download includes source files providing extensive detail about the California EPS data input references.

Data inputs related to costs and prices merit some explanation. Global oil markets are experiencing one of their periodic price shock events. The Russian war against Ukraine is causing much higher expected petroleum fuel prices. The updated California EPS takes current oil price-related effects into account, using the EIA's more current Short Term Energy Outlook (SEO) combined with the less frequently updated Annual Energy Outlook (AEO) for the longer-term trend, starting in 2025.[22]

Short-term variation in fuel price is not a major driver of modeling difference since most EV policy impacts happen after 2025, when petroleum fuel prices in the EPS and analysis for the Draft 2022 Scoping Plan are similar. An appendix provides further detail comparing transportation fuel prices in the EPS, the Standardized Regulatory Impact Assessment recently completed for the Advanced Clean Cars II rulemaking, and the analysis for the Draft 2022 Scoping Plan.

Table 2. Data sources

Sector	References
Cross-cutting	• U.S. Energy Information Administration (EIA), Annual Energy Outlook (2022) • EIA, State Energy Data System (2020)[23] • CARB, Greenhouse Gas Inventory (2019) • E3, California Pathways model outputs (2022)[24] • Rocky Mountain Institute data generated using its state EPS downscaling codebase, which uses public data inputs (including EIA, EPA, BLM)
Electricity	• E3, RESOLVE modeling for California Public Utilities Commission's 2022 long-term planning process[25,26] • California Energy Commission, total system generation
Transportation	• CARB, EMFAC emissions and fleet database[27] • Oak Ridge National Laboratory, Transportation Data book[28] • Argonne National Laboratory, GREET model[29]
Industry	• California Energy Commission, Integrated Energy Policy Report[30] • CARB GHG Inventory plant-level fuel combustion data[31] • EIA Form 860 - Schedule 2, Plant Data, or Combined Heat and Power[32]
Buildings	• National Renewable Energy Laboratory, Electrification Futures: End-Use Electric Technology Cost and Performance Projections Through 2050[33] • California Energy Commission, Integrated Energy Policy Report[34] • California Energy Commission, Building Decarbonization Assessment[35] • California Pathways[36]

SCENARIOS

Scenarios are economy-wide representations of energy use and travel demand along with emissions characteristics of different fuels and technologies, which combine to provide a complete picture of emissions and energy-related spending (covering private spending on capital, fuel, and other operational and maintenance expenses, as well as government budget impacts). The EPS analyzes policy impacts by comparing total energy use, emissions, cost, and other variables under different policy settings. An EPS scenario is created by choosing the policy settings.

The BAU Scenario is the model's foundation, capturing projected changes based on current economic, technological, and population trends. The BAU Scenario includes settled policies, defined as policies with established implementation pathways and statutory authority, while the scenario excludes executive orders or statements of intent not yet backed by legal standing.

Table 3. BAU Scenario

Sector	Assumptions
Cross-cutting	• Includes a carbon price created by the state's cap-and-trade program based on a projection forward of recent price trends, reaching $54/ton in 2030. In 2031 and later years, the carbon price stays constant in this scenario, reflecting the 2030 sunset of explicit legislative authority under SB 398.
Electricity	• Consistent with the CPUC's 2022 decision setting a GHG emissions planning target of 38 million metric tons (MMT) in 2030 for the electric sector, dropping to 35 MMT by 2032. The CPUC's modeling found this results in the use of about 73% Renewables Portfolio Standard resources and 86% GHG-free resources by 2032.[37] • Reflecting the current focus on adding resources contributing to system reliability, BAU electricity system development adds off-shore wind, long-duration storage, and geothermal power.[38] • After 2032, policy requirements approximate SB 100's 2045 carbon-neutrality requirement.
Transportation	• Current Advanced Clear Cars standards through 2025. These are equivalent to average light-duty vehicle tailpipe emissions required under the 2012 federal Corporate Average Fuel Economy standards. • ZEV adoption reaches approximately 5 million in 2030, as in BAU modeling by the Institute for Transportation Studies, University of California, Davis.[39] • The state's Advanced Clean Trucks policy, which sets a ZEV sales standard for medium- and heavy-duty vehicles, reaching about 60% of EVs in new truck sales in 2035. • State and federal EV subsidies. • The state's long-standing Low Carbon Fuel Standard, requiring an overall 20% reduction in carbon intensity in 2030.
Industry	• Process and fugitive emissions fall as required by SBs 617 and 1383, which set statewide emissions targets of 40% below 2013 levels by 2030 for methane and F-gases, and 50% below 2013 levels by 2030 for anthropogenic black carbon. • Cement and concrete sector-related GHG emissions fall 40% below 2019 levels by 2035, induced by SB 596.[vi]
Buildings	• Building energy efficiency calibrated to 2021 Integrated Energy Policy Report's Mid Demand Case for Natural Gas and High Demand Case for Electricity.[40] • Building electrification assumptions reflect the 2022 Scoping Plan Reference Scenario. By 2030, high-efficiency heat pumps comprise at least 15% of building appliance new sales, including replacements in existing buildings. Starting in 2026, 25% of new construction is all-electric.

A second policy scenario, the Committed Policies Scenario, includes a broader array of policies beyond the BAU Scenario's policies with clear statutory authority and enforceability. This Committed Policies Scenario evaluates the combined emissions effects of what policymakers have indicated they want to do, even if the policy approach is not yet clear or backed by law. Transportation stands out as the sector with the greatest momentum and plans for accelerated decarbonization policy.

[vi] SB 596 requires CARB, by July 1, 2023, to develop a comprehensive strategy for the state's cement sector to achieve net-zero emissions of GHGs associated with cement used within the state no later than December 31, 2045. The bill establishes an interim target of 40 percent below the 2019 average GHG intensity of cement by December 31, 2035.

Table 4. Committed Policies Scenario

Sector	Assumptions
Cross-cutting	• Instead of plateauing at $54/ton in 2030, as in the BAU Scenario, the carbon allowance price created by the state's cap-and-trade program continues increasing in 2031 and later years, reaching $258/ton in 2050.
Electricity	• Same as BAU Scenario
Transportation	• Electrification of cars and light trucks: ZEVs grow to 68% of new vehicle sales in 2030, reaching 100% in 2035. This reflects CARB's current proposal for changes to its Advanced Clear Cars program. • Electrification of trucks: electric-drive medium- and heavy-duty trucks reach 100% of new vehicle sales in 2040. • Internal combustion new car and light-truck vehicle efficiency: fuel economy improves 2% annually from 2026 to 2035. • Internal combustion new truck vehicle efficiency: fuel economy grows 2% annually from 2028 to 2035. • Sustainable Communities Strategies, comparable to the EPS's mode-shifting policy level, reduce average vehicle miles traveled per person as in the Proposed Scoping Plan Scenario. Motor vehicle travel demand per person falls by 19% in 2035 and by 22% in 2045 compared to 2019 levels.
Industry	• Same as BAU Scenario
Buildings	• Same as BAU Scenario

Energy Innovation also developed a third policy scenario, the Deeper Decarbonization Scenario, summarized in Table 5. The Deeper Decarbonization Scenario adds economywide policy impetus to substantially lower 2030 emissions below the existing 2030 target. Accelerated emissions reductions are driven by quicker economywide electrification and efficiency improvements. These include faster deployment of renewables and flexible grid investments to hasten power sector decarbonization; using hydrogen and CCS technologies to mitigate the most challenging industry sources; and drawing down process emissions from industry and agriculture beyond the 40 percent reduction in F-gases and methane emissions included in the BAU Scenario to the level called for by SB 617 (2030 emissions reductions below 2013 emission levels).

Eliminating the last 10 percent of fossil generation and maintaining reliability in a zero-carbon grid is the subject of ongoing research. In the Deeper Decarbonization Scenario, existing small natural gas generators—sometimes called peaker plants—run at low and declining capacity factors to provide reliability in addition to battery storage, transmission expansion, and demand response. These remaining fossil stability resources are modeled as being equipped with CCS starting in 2030, capturing associated emissions in full by 2040. Other decarbonized fuels, such as biogas or renewable hydrogen, offer additional approaches to ensuring grid reliability during times of peak demand. The Proposed Scoping Plan Scenario employs yet a different approach, relying heavily on direct air capture machines to extract carbon dioxide from the atmosphere to reach electricity sector carbon neutrality.

Table 5. Deeper Decarbonization Scenario

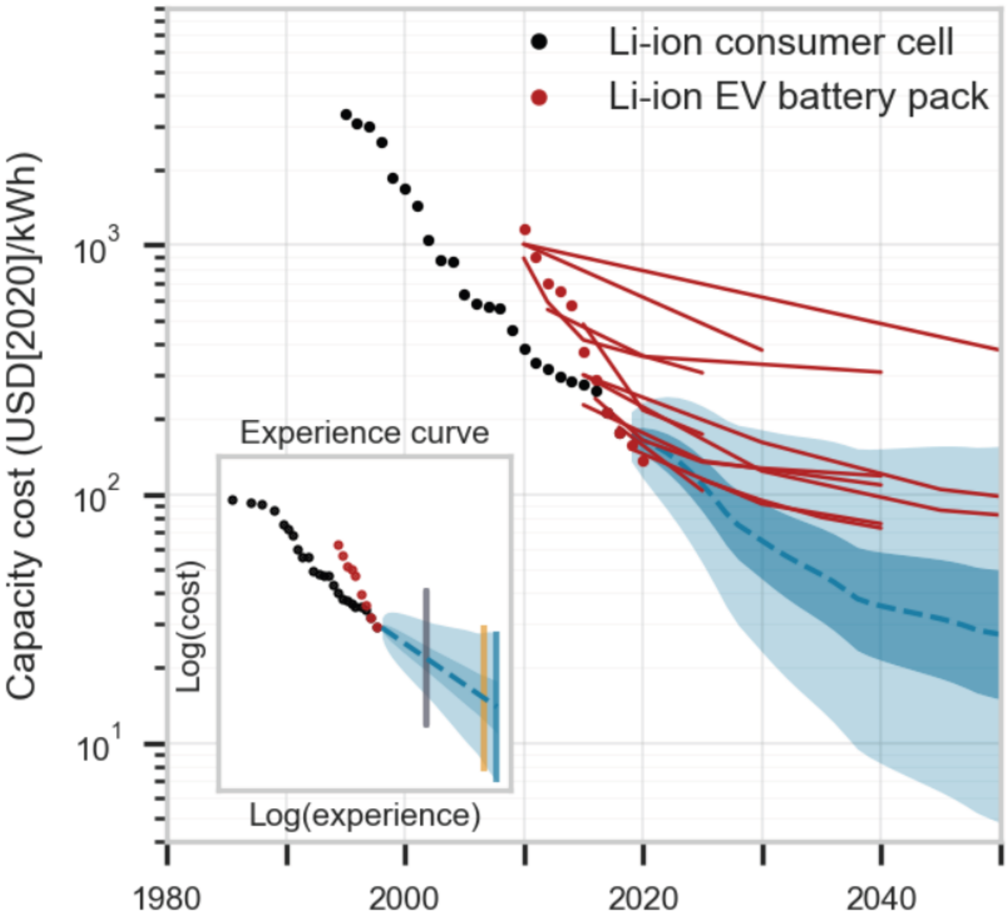
Sector	Assumptions
Cross-cutting	• Same as BAU Scenario
Electricity	• Increase the clean energy standard in tandem with electricity grid reliability investments, reaching around 76 percent renewable electricity and 92 percent clean electricity (compared to retail sales as prescribed by current policy). • Electricity grid reliability investments in this scenario include doubling battery storage capacity, doubling transmission capacity, and adding 5,900 megawatts (MW) of demand response capacity. Associated reliability resource costs are included in clean energy standard policy costs.
Transportation	• Electrification of cars and light trucks: ZEVs reach 100% of new vehicle sales in 2030. • Electrification of medium- and heavy-duty vocational trucks and buses: ZEVs reach 100% of new vehicle sales in 2030. • Electrification of tractor trailer-type freight trucks (colloquially known as "semis"): ZEVs reach 100% of new vehicle sales in 2035.
Industry	• Switching to lower carbon fuels, prioritizing electrification, switching to electricity from fossil fuel combustion. When electrification is technically infeasible or cost prohibitive, industry energy demand switches to hydrogen produced by electrolysis (i.e., using electricity). • Grid-connected electricity supplies hydrogen production in this scenario, in contrast to the 2022 Draft Scoping Plan analysis, which assumes electricity for hydrogen production is from dedicated solar PV facilities, disconnected from the electricity grid. • Emissions reductions even beyond SB 617 requirements for short-lived climate pollutants (detailed in Table 3). Faster phase switch to low global warming potential refrigerants consistent with the Kigali Amendment to the Montreal Protocol. Additional reduction in methane leakage associated with natural gas use. • CCS to capture industrial process emissions otherwise difficult to mitigate in three industries, cement, chemicals, and ferrous metals production. .
Buildings	• Electric building components reach 100% in 2030, covering new buildings and appliance replacements in existing buildings.

LEARNING CURVES

The EPS includes learning curves for batteries and many other key clean technologies, which show that greater technology deployment and performance improvement to lower cost. They capture how greater production and use of emerging technologies lead to learning by doing and economies of scale, predictably boosting innovation.

For EVs, battery costs are the key determinant of competitiveness with internal combustion engine vehicles. Figure 8 illustrates the learning curve effect that led EV battery pack costs to fall 89 percent in real terms over the last decade.[41]

Figure 8. Learning curve for batteries[vii] [42]



In addition to depicting real-world learning curve effects for batteries, Figure 8 illustrates how energy forecasts have consistently underestimated future innovation. The steeper cost declines in real-world trends compared to forecasts show how influential energy-economy modelers such as the International Energy Agency have failed to anticipate continued innovation repeatedly.

Analysts predict that battery pack prices will increase this year, reflecting raw material price pressures. California's Lithium Valley is an example of a global surge in prospecting for new sources and cleaner methods. The California Energy Commission's Lithium Valley Commission is underwriting efforts to pioneer sustainable extraction of lithium contained in the briny waters of the Salton Sea. Demonstration projects are developing promising new ways to harvest lithium in tandem with geothermal electricity production. Estimates suggest that Salton Sea-area resources could generate yearly output of 600,000 tons of lithium carbonate per year, roughly equal to current global production and worth about $7 billion per year at current prices.[43]

[vii] Black data points represent historical values for consumer batteries, and red data points show historical values for EV batteries. Red curves show past cost forecasts. The blue cone shows the expected future trend. The smaller inset graph shows the same historical data transformed using a logarithmic function. Sometimes this approach is preferred because it results in a straight trend line representing a constant percentage change over time.

In addition, new advanced battery chemistries, with solid state batteries as the next frontier, will likely feed the next commercially viable battery technology, and novel chemistry formulas will lessen demand for existing options.

Finally, additional economies of scale will support innovation and falling battery costs. While only a few large battery factories have been built worldwide, and global capacity will double several times over in coming decades. Economic history and insights from the interdisciplinary field of learning curves both signal that production costs are highly likely to continue falling.

Any 2022 pause in the downward march of battery prices will likely be temporary and not a signal of a break in the trend, when understood in context. In the coming months and years, myriad new investments in lithium resources will start to produce raw material, reducing short-term cost pressures. Furthermore, new battery technologies and opportunities related to economies of scale provide confidence that cost improvements will continue over the next five to ten years. The California EPS model's internally calculated learning curve effects imply that battery costs will fall by about 42 percent from 2020 to 2030.

RESULTS

The results section presents scenario analysis, evaluates individual policy impacts, compares EPS modeling to analysis underlying the Draft 2022 Scoping Plan, then closes with focused investigation of two transportation policies: EV sales standards and mode shifting.

EPS SCENARIO ANALYSIS

Scenario results begin with graphs of sectoral emissions in the BAU and Committed Policies scenarios. Transportation emissions fall more quickly in the Committed Policies Scenario. This effect is from additional vehicle electrification and more successful Sustainable Community Strategies ("mode shifting" in the EPS). These measures reduce development patterns that induce motor vehicle dependency by investing in walkability, bicycle transportation infrastructure, and public transit, resulting in moderated motor vehicle travel demand.

Whether considering the BAU Scenario or the Committed Policies Scenario, California EPS 3.3.1 results illustrate the gap between state targets and current emissions trends. By way of reorientation, SB 32's 2030 target of 40 percent below 1990 emissions levels implies that state inventory emissions must fall below 260 MMT of CO_2e by 2030. The figures below illustrate the 2030 compliance gap—the difference between California's targets and expected emissions in the BAU Scenario (Figure 9) and Committed Policies Scenario (Figure 10). With 307 MMT of CO_2e emissions in 2030, the Committed Policies Scenario reduces emissions 31 MMT below the BAU Scenario, but emissions remain nearly 50 MMT, or 20 percent, above the 2030 target.

Figure 9. Sector emissions in the BAU Scenario

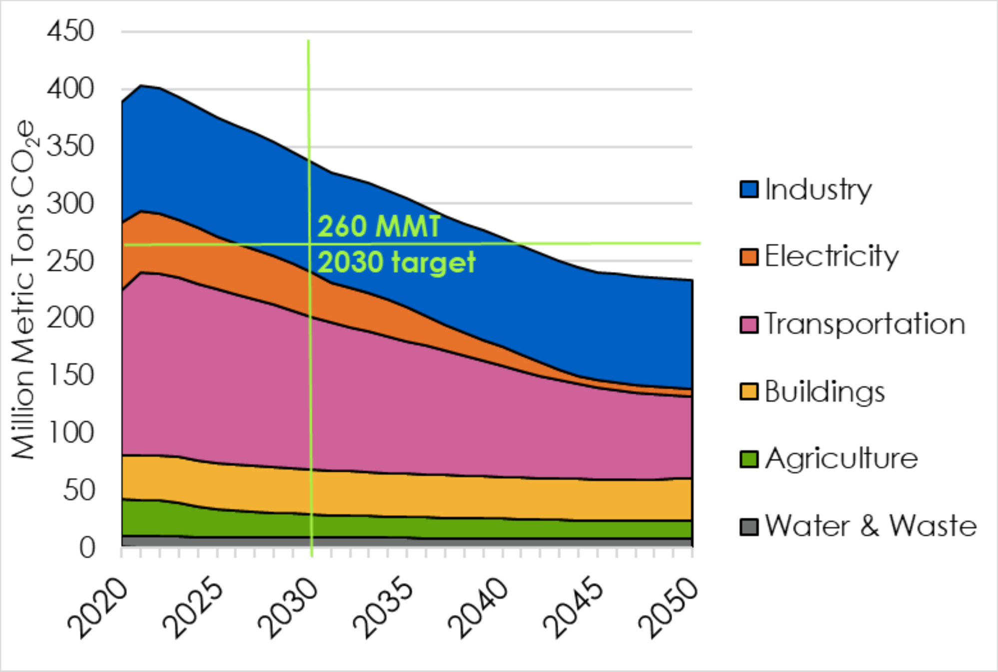
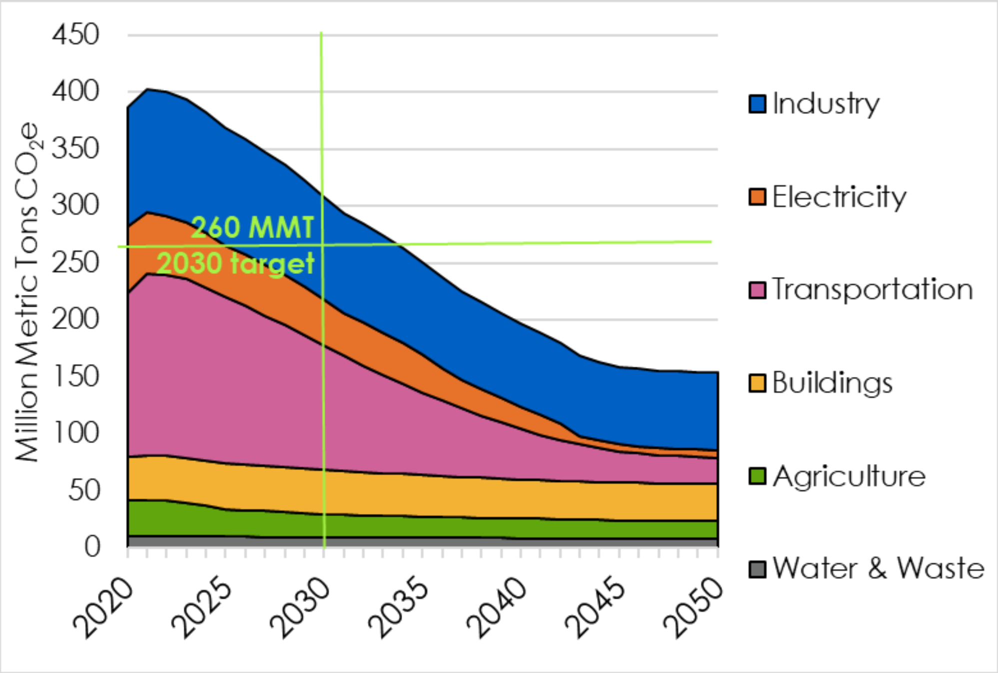


Figure 10. Sector emissions in the Committed Policies Scenario



We turn next to the California EPS's Deeper Decarbonization Scenario, which Energy Innovation developed to achieve and go beyond the minimum required 2030 emissions reductions. As illustrated in Figure 11, the Deeper Decarbonization Scenario combines policies across sectors to reduce emissions faster, lowering 2030 emissions to 230 MMT of CO_2e, 46 percent below 1990 levels. Deeper Decarbonization Scenario emissions fall to 130 MMT of CO_2e in 2035, 70 percent below 1990 levels, further dropping to 49 MMT of

CO_2e in 2045. In 2018, Executive Order B-55-18 set the goal of reaching carbon neutrality by 2045, which the Deeper Decarbonization Scenario does not quite reach. This is due, in part, to uncertainty about future available technology to mitigate industrial emissions and continued global demand for fossil fuels. With further consideration, and certainly as technology develops in the coming years, California will be able to address these emissions.

Figure 11. Sector emissions in the Deeper Decarbonization Scenario

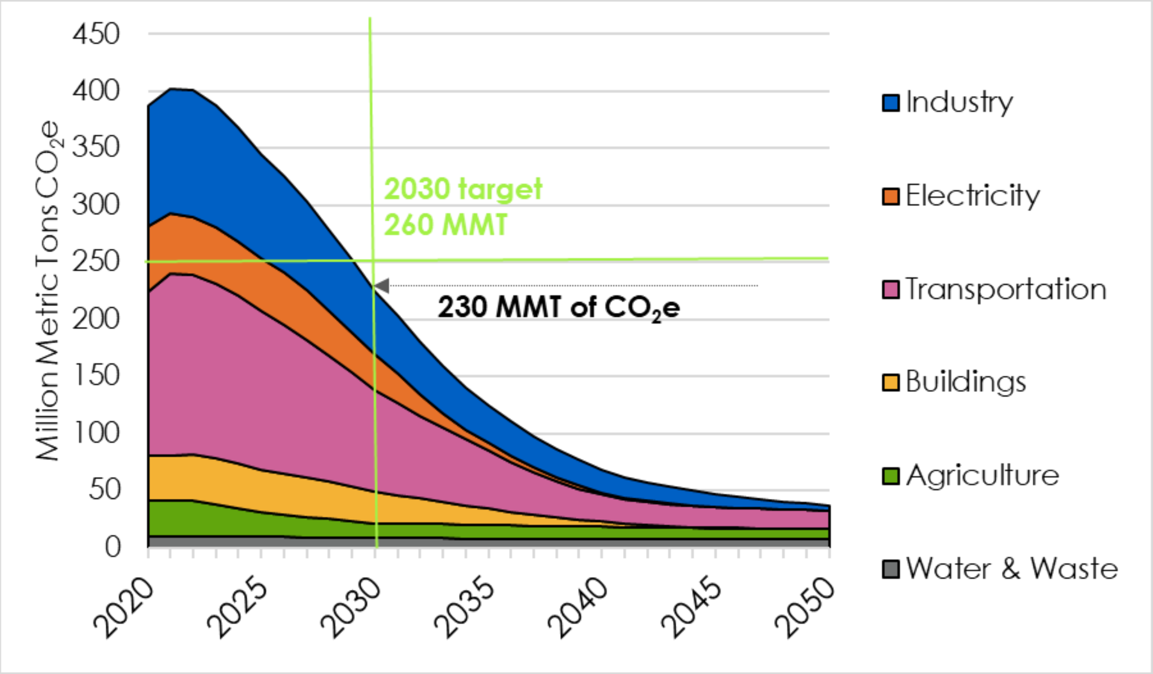


Table 6. Emissions and emissions reductions as percentage of 1990 emissions levels (431 MMT of CO_2e)[viii]

	2030		2035		2045	
	Emissions (MMT CO_2e)	Reductions (% below 1990)	Emissions in (MMT CO_2e)	Reductions (% below 1990)	Emissions in (MMT CO_2e)	Reductions (% below 1990)
BAU Scenario	336	22%	323	25%	312	28%
Committed Policies Scenario	308	29%	284	34%	262	39%
Deeper Decarbonization Scenario - CCS excluded	232	46%	136	69%	66	85%
Deeper Decarbonization Scenario	230	47%	130	70%	56	87%

[viii] For each year, the table lists total emissions in two ways, using a mass-based measure (MMT of CO_2e) and expressing emissions as a share of 1990 emissions, which SB 32 uses as compliance benchmark in setting a 2030 target of 40 percent below 1990 emissions levels. This table, and this research in general, focus on energy and other industrial emissions, i.e., those included in the state's GHG emissions inventory, excluding those related to land change (referred to as natural and working land emissions in California climate policy).

Turning from emissions reductions to other policy impacts, California EPS results indicate the Deeper Decarbonization Scenario delivers significant economic and social benefits. Figures 12-15 offer eight data visualization depicting job creation, affordability, stronger and higher-quality economic growth, and public health benefits. Figure 12 presents economic and household affordability benefits, which are largely driven by energy-saving investments for more energy-efficient capital, including electrification, because electric motors and heat pumps for heating and cooling are more efficient than their fossil counterparts. Monetized social benefits in Figure 13 are the sum of climate benefits (using the U.S. Social Cost of Carbon) and avoided premature mortality estimated using economic valuation methods.[44]

Regarding job creation shown in Figure 14, additional policies not modeled by the EPS would be necessary to ensure communities historically reliant upon or harmed by the fossil fuel economy benefit from high-quality jobs paying fair wages. Policy can support a sustainable, equitable, and just transition by considering impacted communities when choosing the location of new clean energy infrastructure projects. Policymakers can also create training programs to equip transitioning workers with the required skills, among other efforts. Other social policies can provide for basic needs such as healthcare or financial assistance to ease the transition.[45]

Looking at historical data provides some measure of validation for the finding that stronger policies in the Deeper Decarbonization Scenario will yield job creation. EV manufacturing jobs in California have risen to about 19,000, double the state's historical level of auto manufacturing jobs going back decades.[46] Overall, the EV industry has created more than 275,000 direct jobs paying an annual average income of $91,300, according to the Los Angeles County Economic Development Corporation.[47]

Figure 15 profiles health benefits, focusing on avoided premature death. Considering that fuel combustion and industrial processes are the main sources of local air pollutants, the significant health benefits from the Deeper Decarbonization Scenario are intuitive. Less fossil fuel power generation, emissions-free building appliances, zero-emission on-road vehicles, and industrial fuel switching all reduce harmful particulate emissions and secondary atmospheric pollution created by burning fossil fuels.

Figure 12. Economic benefits attributable to the Deeper Decarbonization Scenario

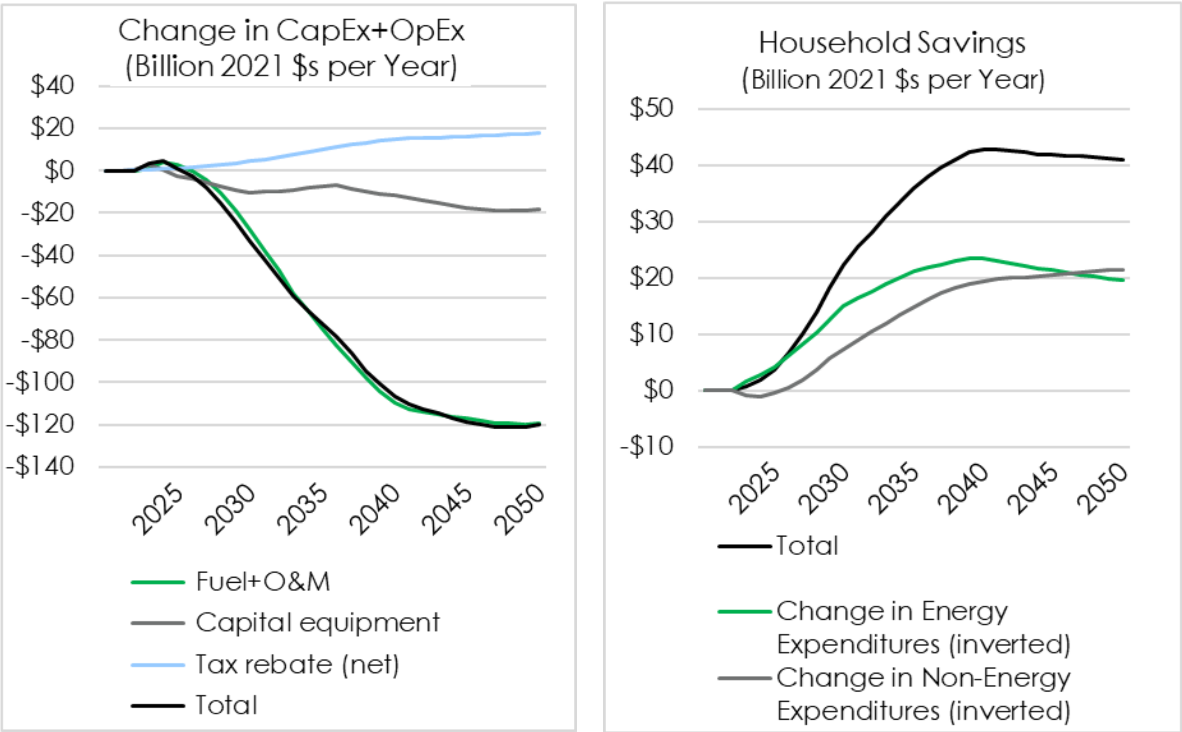


Figure 13. Macroeconomic and monetized social benefits attributable to the Deeper Decarbonization Scenario

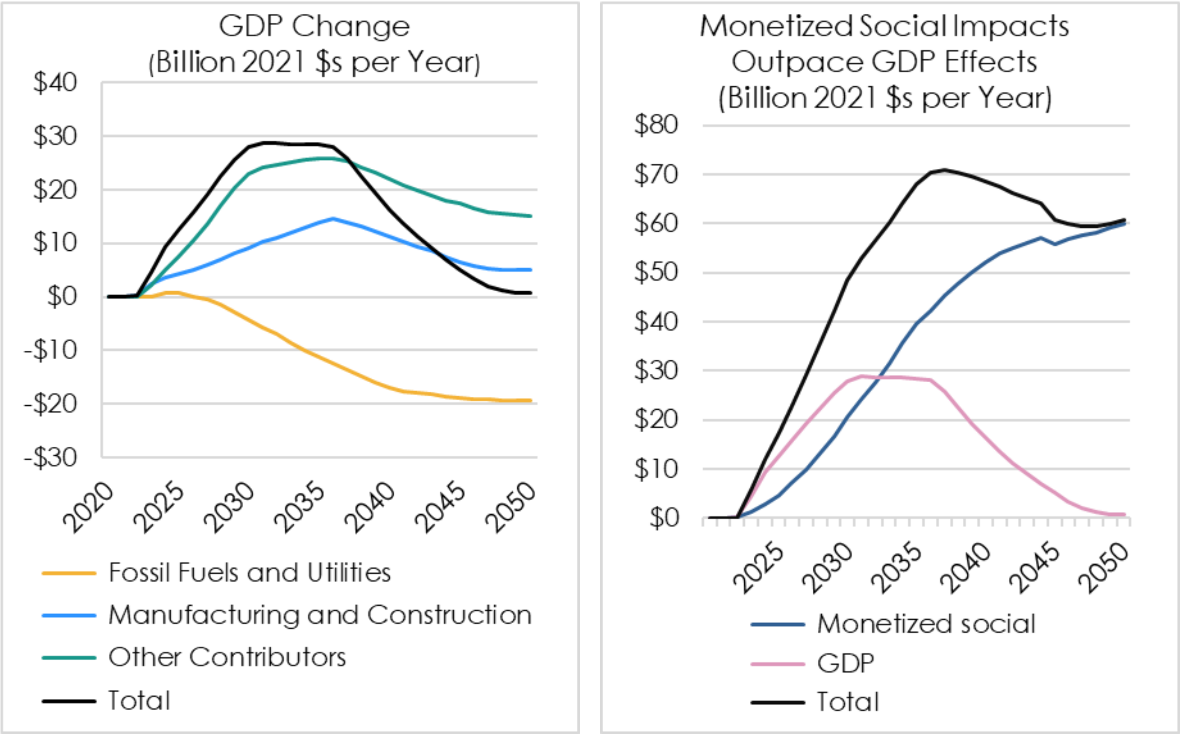


Figure 14. Job creation attributable to the Deeper Decarbonization Scenario

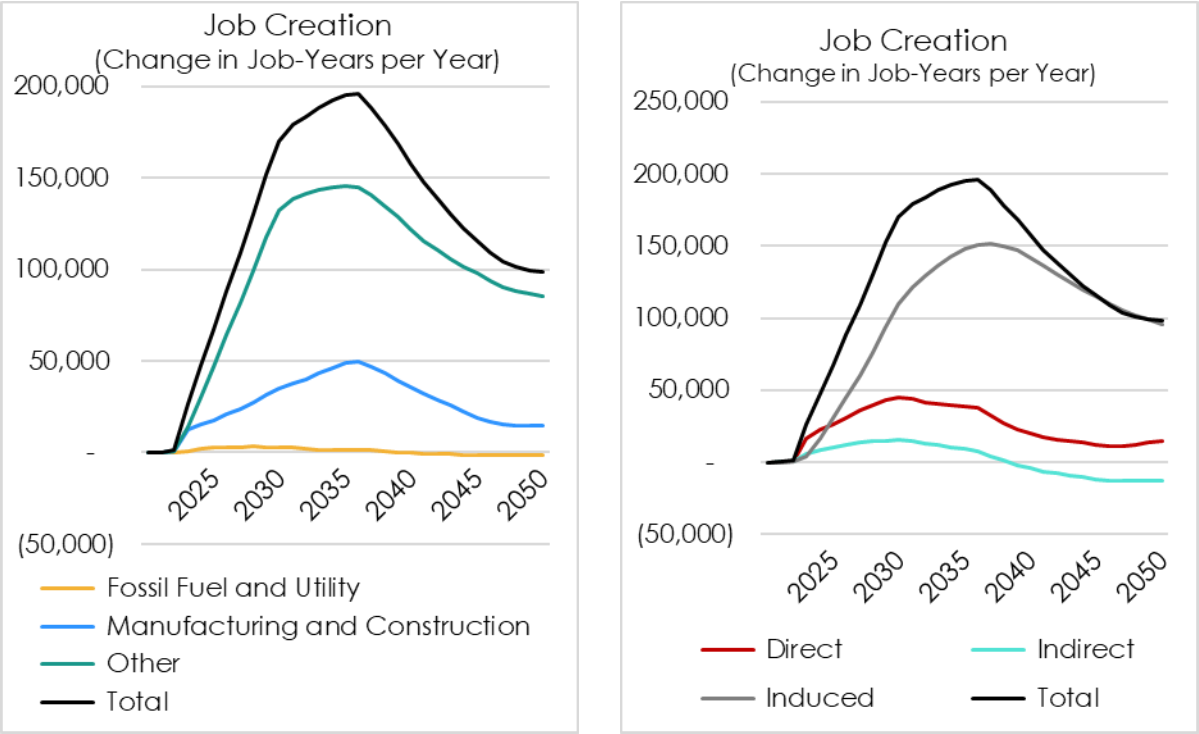
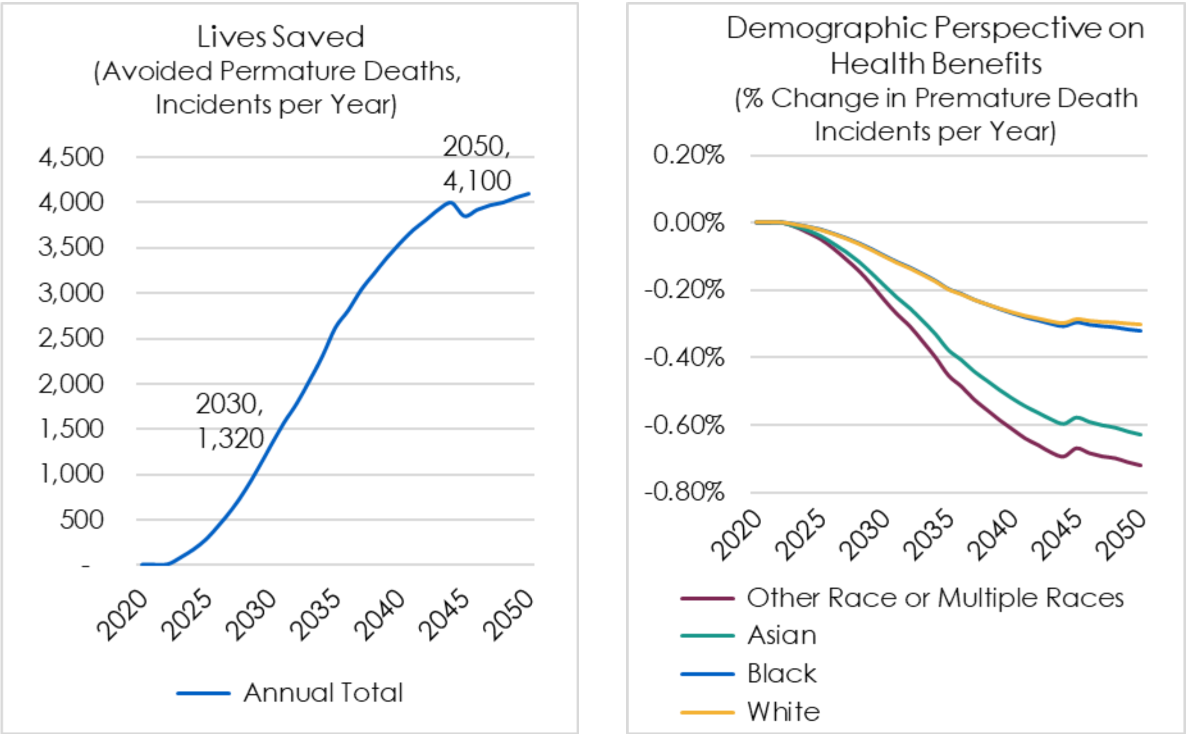


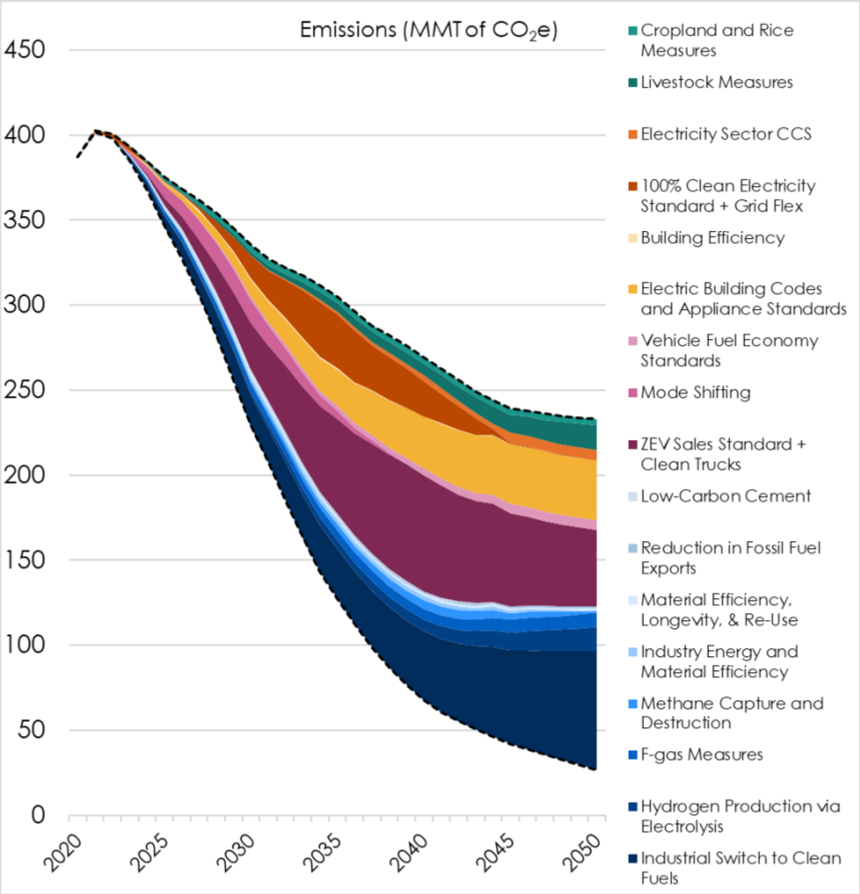
Figure 15. Health benefits attributable to the Deeper Decarbonization Scenario



INDIVIDUAL POLICY ANALYSIS

EPS results demonstrate the cross-sectoral importance of electrification, which emerges as a significant policy in each major sector. Policy interactions drive the large emissions reductions resulting from an incremental increase in the clean energy standard, whose effect is magnified by the proliferation of EVs and electric heat pumps.

Figure 16. Policy wedges—average annual policy abatement in Deeper Decarbonization Scenario[ix]



Two data visualizations frame the discussion of the impacts of individual policies in the Deeper Decarbonization Scenario.[x] A policy wedges diagram, Figure 16, shows annual emissions reductions attributed to individual policies. An abatement cost curve, Figure 17, offers perspective on emissions

[ix] Note: Figures 16 and 17 aggregate results of some policy levers to improve figure readability; a full wedge graph and abatement cost curve are available on the California EPS webpage. Both figures also exclude the petroleum fuel export reduction policy. The EPS internally recalculates petroleum refining and imports, accounting for lower demand with increasing deployment of EVs. The Deeper Decarbonization Scenario and Policy Commitments Scenario use the fossil fuel exports reduction policy to lower petroleum fuel exports in line with changes in domestic production levels. This exports adjustment is likely to be automated in future EPS model updates and is considered a structural system correction. Hence, while the policy is observable in the web app, the abatement cost curve in this report excludes the change.

[x] As discussed under Methodology, the EPS calculates policy impacts as the difference metrics in the Deeper Decarbonization and BAU scenarios.

reductions and cost effectiveness of individual policies. A policy's cost effectiveness is measured as the NPV of spending impacts divided by emissions reductions, either through 2030 or 2050. The width of each policy's bar represents its average annual emissions reductions through either 2030 or 2050. The height of each policy's bar indicates the average cost per ton, with values below the horizontal axis representing cost-saving policies.

Figure 17. Abatement cost curve for policies in the Deeper Decarbonization Scenario

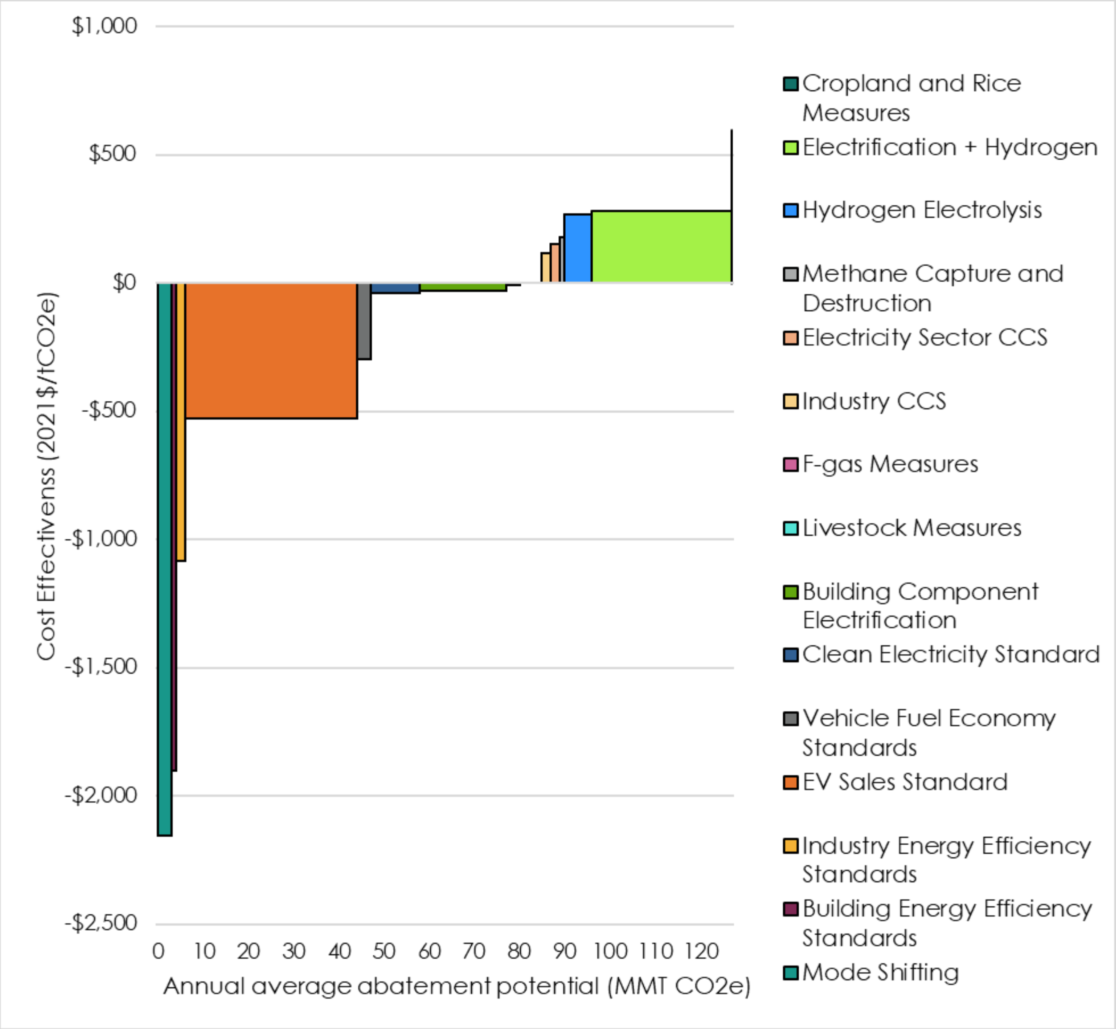


Table 7, next, shows 2030 and 2050 abatement cost curve results for the policies with the largest emissions reductions in each sector, ranked by abatement potential. The Clean Energy Standard has a larger abatement effect than building electrification in 2030, but the effects of building electrification grow more quickly. The buildings policy depends on sales for new buildings and appliance replacements, which is a factor limiting effectiveness in the near term. Over time, more and more of the capital stock turns over, magnifying the effect of building electrification

Table 7. Top policies in Deeper Decarbonization Scenario ranked by abatement potential

	Decarbonization effectiveness (average annual abatement)	Cost effectiveness (NPV of average cost per tonne abated)
2030 Results		
EV Sales Standard	8.2 MMT of CO_2e	−$776 per tonne
Electrification + Hydrogen	7.5 MMT of CO_2e	$927 per tonne
Clean Energy Standard	3.2 MMT of CO_2e	$366 per tonne
Building Electrification	3.0 MMT of CO_2e	$23 per tonne
2050 Results		
EV Sales Standard	38.3 MMT of CO_2e	-$527 MMT of CO_2e
Electrification + Hydrogen	30.8 MMT of CO_2e	$280 MMT of CO_2e
Building Electrification	19.3 MMT of CO_2e	-$29 MMT of CO_2e
Clean Energy Standard	11 MMT of CO_2e	-$42 MMT of CO_2e

The economic benefits of ZEV policies evident in these tabular results are due to lower costs for fuel and maintenance. Today, EV purchase prices are above those of comparable internal combustion engine vehicles but, since nearly all vehicles are financed, differences in sticker price are not the best measure of initial cost differences. Even accounting for increased financing costs due to higher purchase prices, most EVs provide total ownership savings (e.g., accounting for vehicle, fuel, maintenance, financing, and insurance costs) immediately.[48] Further, over the next several years, EVs will reach and surpass purchase price parity due to learning curve effects. The Appendix offers further discussion of transportation fuel and vehicle purchase prices underlying results.

Higher 2030 costs for most policies reflect the shortened payback period and the financial profile for many decarbonization investments, involving early capital requirements that pay off with a stream of energy savings overtime. Cutting off some future savings worsens economic performance compared to a longer time frame such as 2050, which allows full lifetime benefits to accrue.

Understanding how the EPS's system dynamics framework tracks interactive effects helps explain the cause-effect origins of Deeper Decarbonization Scenario results. Individual policy impacts are calculated based on the effect when the policy is removed from the package. In other words, the model performs several runs to disable—or turn off—each policy and calculates the resulting emissions effect. The EPS uses this "disabling" method to create the policy wedge diagram and the abatement cost curve figures in this report and available through the web app.[xi]

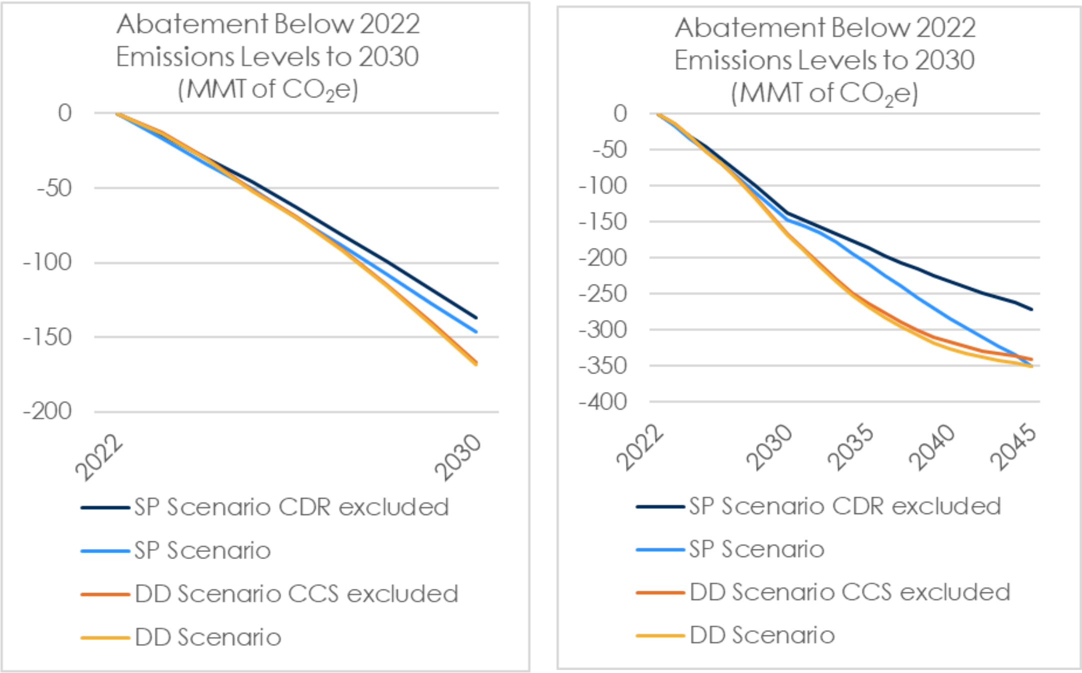
[xi] A policy package's impacts on a policy-by-policy basis can be estimated in one of two ways: by measuring the effect of each policy with none of the other policies activated, or by measuring the effect of disabling a given policy on the emissions reductions

A system dynamics evaluation spotlights large emissions reduction returns to moderate strengthening of the clean electricity standard. Growing electrification means larger emissions reductions are foregone when the EPS disables the clean energy standard for policy impact analysis.

COMPARATIVE ANALYSIS TO PROPOSED SCOPING PLAN

Discussion of results in comparison to the Proposed Scoping Plan Scenario are based on California PATHWAYS model outputs released with the Draft 2022 Scoping Plan, considering energy and industrial process emissions included in the statewide inventory.[49] Comparative analysis focuses on reductions compared to 2022 levels for greatest commensurability.[xii] Figure 18 illustrates emissions reductions in the Deeper Decarbonization and Scoping Plan scenarios, with and without CDR.

Figure 18. Abatement below 2022 emissions in Deeper Decarbonization (DD) and proposed Scoping Plan (SP) scenarios



achieved by the remaining policies. The first method measures emissions reductions that result in the absence of any of the policies, while the second method measures emissions reductions lost when a single policy is disabled from the full portfolio. Since the second approach accounts for policy interaction, the California EPS uses the disabling method.

[xii] Comparative analysis focuses on emissions reductions compared to 2022 levels to avoid introducing confounding effects stemming from different modeling assumptions. One difference between EPS and PATHWAYS modeling involves the feasible start year for emissions reductions. The proposed Scoping Plan Scenario shows some emissions reductions in 2021 and 2022 below the PATHWAYS BAU Scenario. EPS scenarios initiate reductions in 2023 at the earliest. A second difference concerns BAU Scenario emissions assumptions considering the 15.6 MMT of CO_2e difference between PATHWAYS emissions data and CARB's inventory data for 2019 (respectively, 402.6 MMT of CO_2e in the 2022 California PATHWAYS' BAU Scenario vs. 418.2 MMT of CO_2e). After significant investigation, we have not established the reason for this divergence between historical inventory and PATHWAYS data. Focusing on emissions reductions lessens variations causes by different modeling assumptions. Incidentally, economy-wide decarbonization analysis involves countless details, and it is not always possible to document every assumption. Noting this possible discrepancy is not intended as an indication of subpar work, but is necessary to explain the decision to focus on emissions reductions in comparisons.

Table 8. Emissions reductions in Deeper Decarbonization and Proposed Scoping Plan scenarios[xiii]

	2030		2035		2045	
	Reductions below 2022 emissions (MMT CO_2e)	Reductions as % below 2022 emissions	Reductions below 2022 emissions (MMT CO_2e)	Reductions as % below 2022 emissions	Reductions below 2022 emissions (MMT CO_2e)	Reductions as % below 2022 emissions
Proposed Scoping Plan Scenario - CDR Excluded	137	37%	186	50%	272	73%
Proposed Scoping Plan Scenario	147	39%	209	56%	351	94%
Deeper Decarbonization Scenario - CCS Excluded	167	42%	263	65%	340	85%
Deeper Decarbonization Scenario	168	42%	268	67%	350	87%

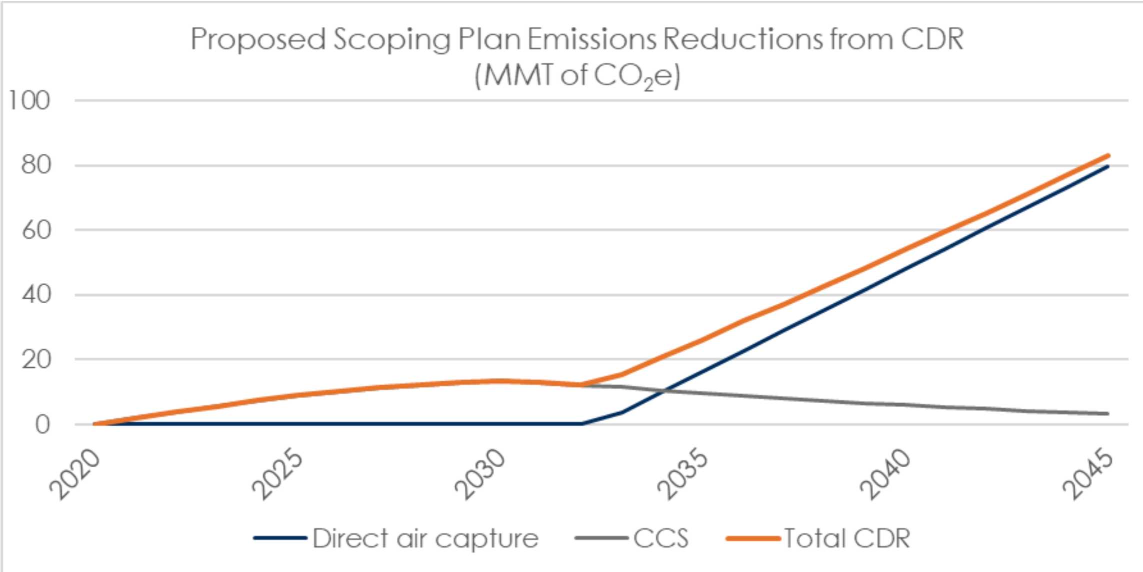
Table 8 shows projected emissions reductions in the Deeper Decarbonization and Proposed Scoping Plan scenarios in tons avoided and as a percentage of the 1990 emissions benchmark used in setting 2020 and 2030 targets. Emissions reductions are greatest in the Deeper Decarbonization Scenario, except in the 2045 comparison, when Scoping Plan Scenario emissions reductions are larger, contingent on assuming success of still unproven mechanical CDR technology. In 2045, the Scoping Plan Scenario compensates for energy and industrial emissions using direct air capture to compensate for 80 MMT of CO_2e in energy and industrial emissions.[xiv] The Deeper Decarbonization Scenario does not utilize direct air capture but does selectively deploy CCS for the industrial sources most difficult to address otherwise. CCS accounts for emissions reductions of 1.5 MMT CO_2e in 2030, 6 MMT CO_2e in 2035, and 10 MMT CO_2e in 2045 in the Deeper Decarbonization Scenario.

The Scoping Plan Scenario emphasizes CCS in early years, with CCS-related emissions reductions peaking in 2030 and tailing off thereafter, reflecting cleaner industrial energy use over time, which reduces emissions available for capture by CCS. The Scoping Plan Scenario shows direct air capture demonstration projects beginning to reach meaningful scale in 2032, growing to around 80 MMT of CO_2e in 2045. Figure 19 breaks down the contributions of CCS and direct air capture to CDR-related emissions reductions in the Scoping Plan Scenario.

[xiii] The table focuses on emissions reductions below 2022 levels to lessen confounding effects from different BAU assumptions – the California EPS estimates 2022 emissions to be 401 MMT of CO_2e vs. 372 MMT of CO_2e in the Scoping Plan analysis BAU Scenario. For each year, the table details emissions reductions below 2022 emissions levels measured by mass (MMT of CO_2e) and as a percentage reduction below 2022 emissions levels found in each modeling exercise.

[xiv] This note offers some context for the 80 MMT of CO_2e in emissions reductions from CDR in 2045 attributed to the proposed Scoping Plan Scenario, which may otherwise appear to diverge from analysis supporting 2022 Scoping Plan development. The small divergence with the total of 83 MMT of CO_2e in CDR-attributable emissions reductions in the Scoping Plan Scenario evident in PATHWAYS model outputs stems from the evaluation of reductions relative to 2022 emissions. The Scoping Plan Scenario deploys CCS capturing 3.7 MMT of CO_2e in 2021 and 2022, which are excluded from the calculation of emissions reductions relative to 2022 emissions.

Figure 19. Emissions reductions from CCS and direct air capture (DAC) in the Proposed Scoping Plan Scenario[50]



SUSTAINABLE COMMUNITY STRATEGIES SENSITIVITY ANALYSIS

In the EPS, mode shifting is analogous to what are referred to as Sustainable Community Strategies in California policy: a collection of methods for lowering the need for motor vehicle travel and reducing CO_2e emissions. These strategies encompass a range of measures: encouraging the development of transit-oriented and walkable neighborhoods close to jobs, upgrading infrastructure for pedestrians and bicyclists, improving public transit quality and convenience, and increasing the availability of urban green spaces.

The Deeper Decarbonization Scenario approximates the approach used in the Scoping Plan Scenario for modeling Sustainable Community Strategies, lowering passenger car and light truck vehicle miles traveled by 12 percent in 2030 and 22 percent in 2045, in per capita terms. Considering BAU trends in passenger car and light truck miles traveled and population, the EPS's Deeper Decarbonization Scenario calibrates mode shifting to cause a 26 percent reduction in total passenger travel demand in 2045. The sensitivity scenario developed in this section achieves a 30 percent reduction in total passenger vehicle miles traveled by 2030. So, in this sensitivity scenario, Sustainable Community Strategies are calibrated to be stronger and to ramp up to full strength in less than half the time of the Scoping Plan Scenario.

California EPS results, both updated and original, show Sustainable Community Strategies to have an attractive impact profile. Mode shifting causes emissions reductions that save many hundreds of dollars per ton—saving among the most costs of any policy considered. And these results do not even consider the economic benefits from consumers wasting less time in traffic (a productivity drag), much less quality of life or public health benefits associated with more active lifestyles.

Figure 21 and Figure 22 show annual and cumulative impacts of the stronger mode shifting policy.[xv] Annual emissions reductions grow to more than 10 MMT of CO_2e annually and more than 120 MMT of CO_2e

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xv These impact estimates are not directly comparable to individual policy impacts shown in wedge diagrams or abatement costs curves the EPS produces, which use the "disabling" method. The results in this figure are calculated as follows: First, we use the California EPS to evaluate impacts of mode shifting in the Deeper Decarbonization Scenario compared to the BAU Scenario and then under mode-shifting per the Sensitivity Scenario compared to the BAU Scenario. Second, the effect of the stronger mode cumulatively (summing annual effects 2023-2040). Emissions and other benefits peak on a yearly basis in the 2030s because of increasing transportation electrification in the BAU Scenario, which reduces the effect of additional mode shifting. Annual lives saved due to avoided premature death from air pollutant exposure reach a maximum of 276 per year, adding up to 3658 through 2040. Economic benefits also add through 2040 with the boost to GDP amounting to more than $100 billion and employment effects showing more than 700,000 jobs created cumulatively.

Based on such an attractive potential benefit profile, Sustainable Community Strategies ambitions are justifiably high. Still, in terms of compliance with the 2030 and other targets, some caution is warranted vis-à-vis how expected performance is represented in modeling. The limits of statewide authority have so far led to fewer reductions than targeted, posing feasibility questions about Sustainable Community Strategies.

CARB did not mince words in a 2018 assessment: “A key finding of this report is that California is not on track to meet the GHG reductions expected under [SB] 375 for 2020, with emissions from statewide passenger vehicle travel per capita increasing and going in the wrong direction.”[51] The most recent update finds continued shortfalls of performance compared to targeted policy effects, concluding, “California is still not reducing GHG emissions from personal vehicle travel as needed under SB 375.”[52]

The mode-shifting effects achieved in this sensitivity scenario would represent unprecedented shifts compared to patterns slow to change observed over the last decades. Emissions reductions from mode-shifting in the Deeper Decarbonization Scenario are already pushing the limits of feasibility. Note that the original California EPS research on the 2017 Scoping Plan was more cautious about prospects for mode-shifting or Sustainable Community Strategies success. The original California EPS modeling represented as half as effective compared to modeling CARB procured to support the 2017 Scoping Plan.[53]

shifting policy is calculated as the difference between a given metric in the Deeper Decarbonization Scenario vs. the Sensitivity Scenario.

Figure 20. Sustainable Community Strategies sensitivity scenario annual impacts

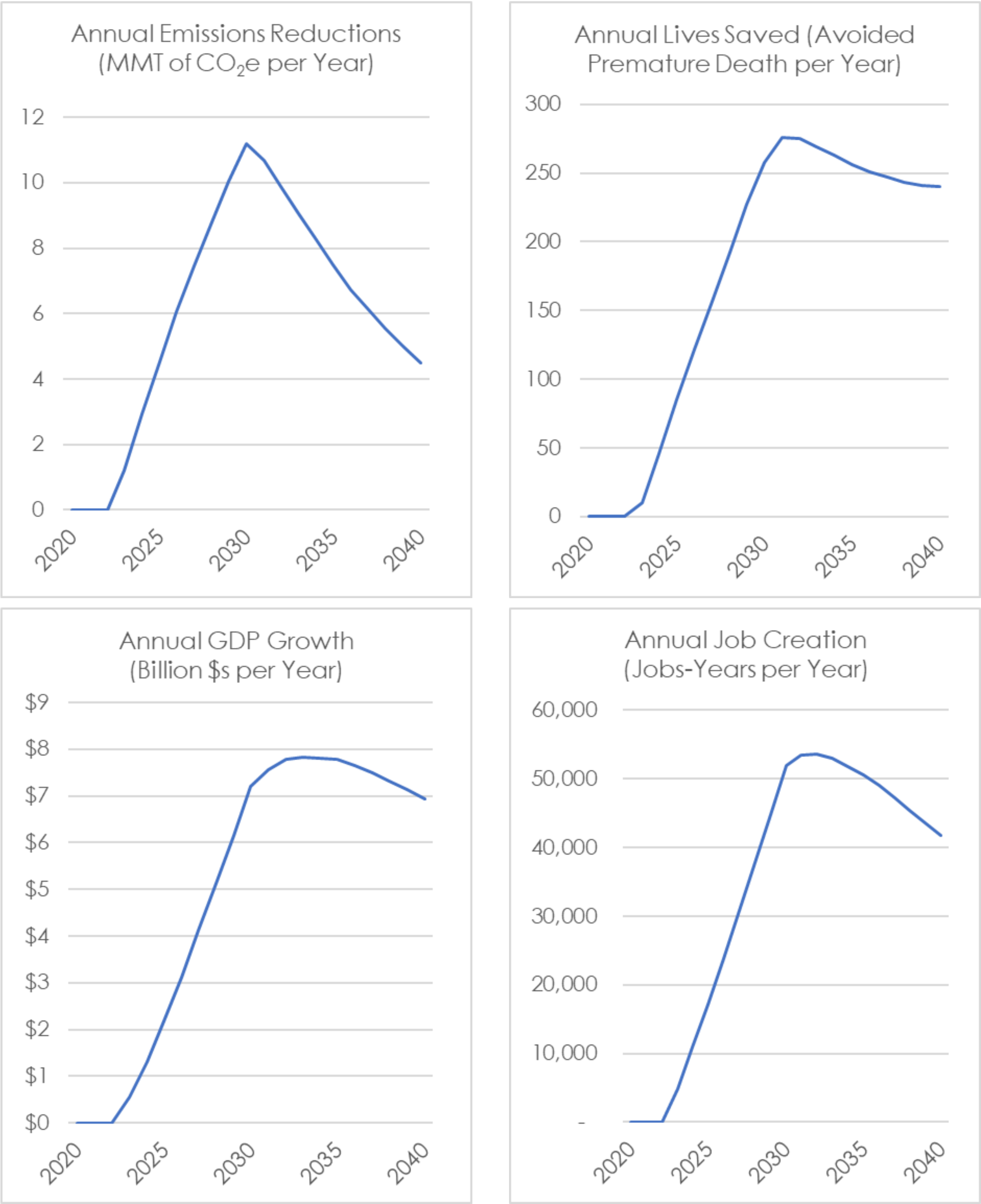
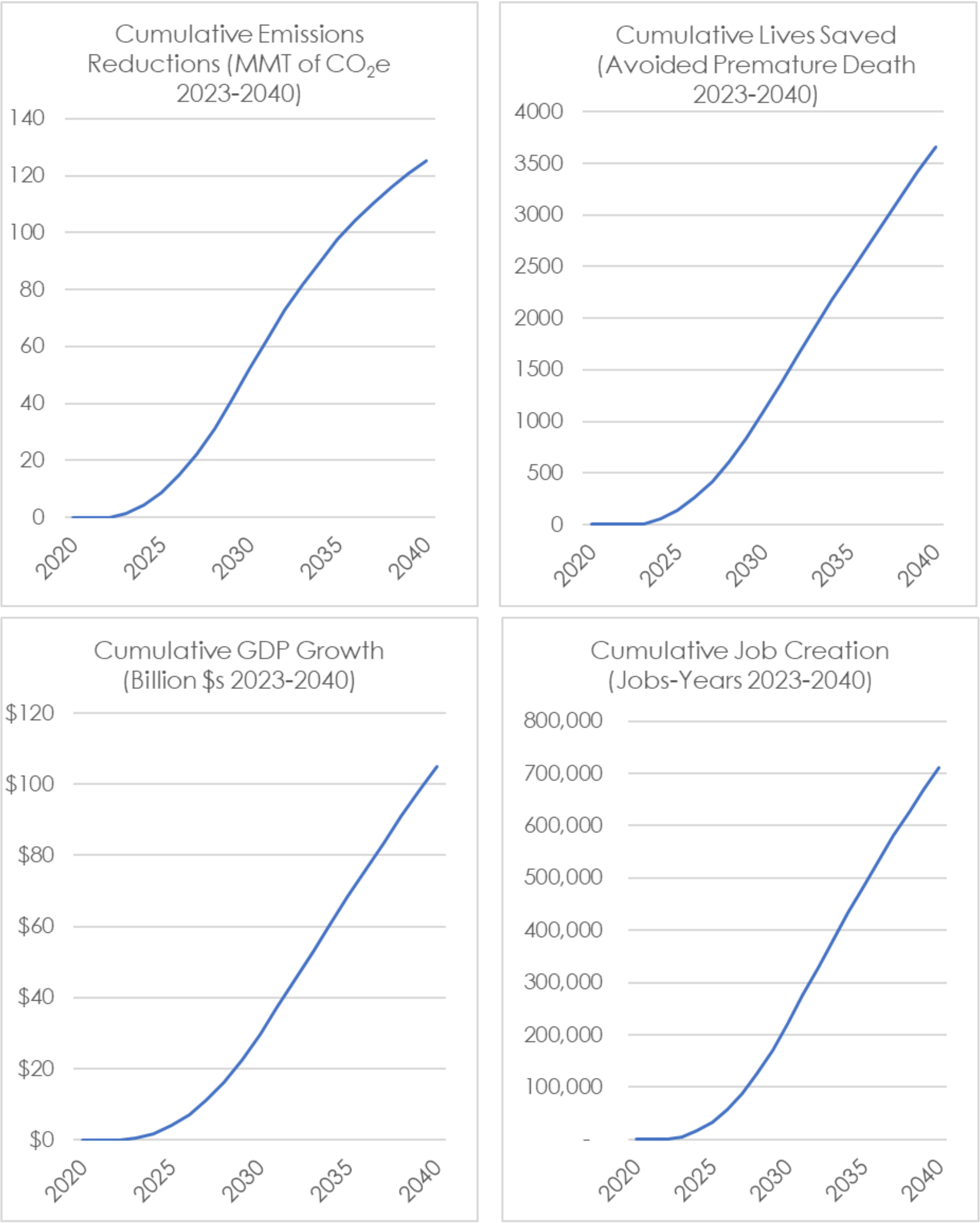


Figure 21. Sustainable Community Strategies sensitivity scenario cumulative impacts (2023-2040)



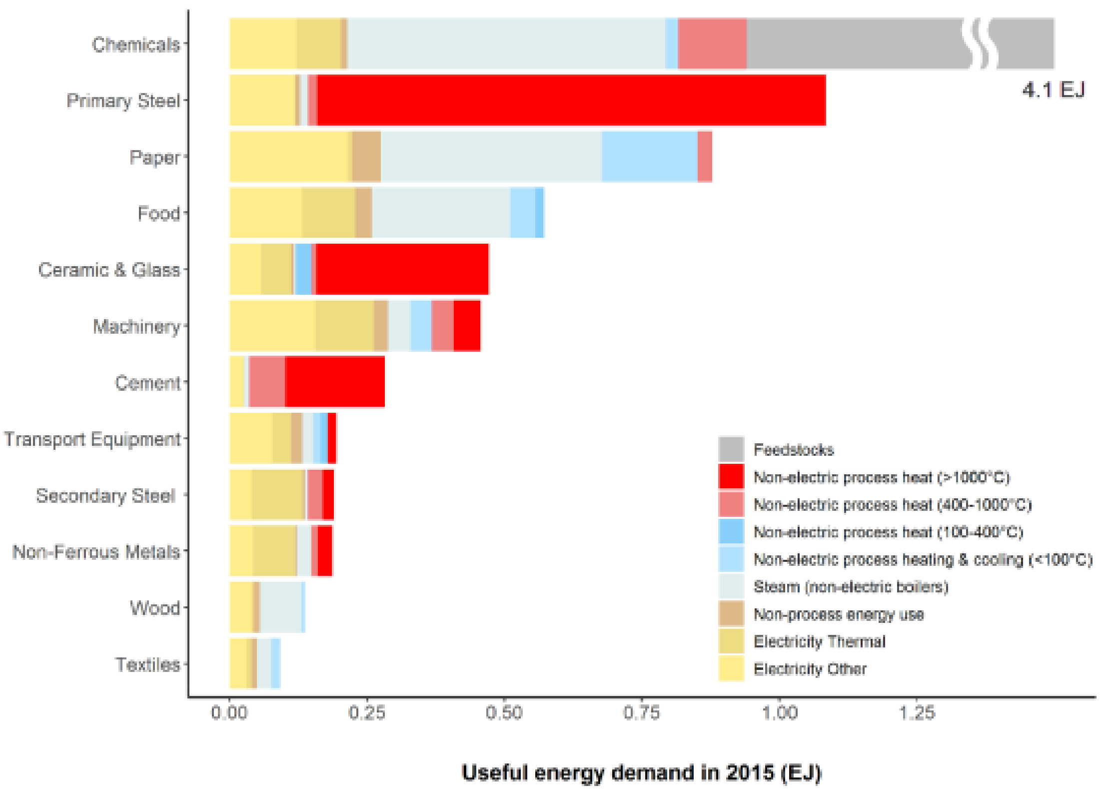
DISCUSSION

UNTAPPED INDUSTRIAL DECARBONIZATION POTENTIAL CASE STUDY

This case study highlights food and beverage processing as a promising industry to consider for electrification based on emissions reduction opportunity and technical feasibility.

Starting with the technical feasibility: Low temperature demand makes the food and beverage processing sector a prime candidate for decarbonization. Food and beverage processing stands out for its demand for low-temperature heat, which could be met with existing heat pump technology. Figure 22 presents evidence that the food and beverage processing industry has among the most easily serviceable, least extreme heat demand profile of any industry.

Figure 22. Industry breakdown shows that food processing demands lower temperature heat[54]



Food and beverage natural gas combustion is responsible for more than 3 MMT of CO_2e emissions in the 2019 state inventory.[55] As noted above, The table below ranks the top industrial users of natural gas in California based on data from Energy & Environment's California Pathways model, vintage 2017, showing the food and beverage processing industry to be California's third-largest industrial user of natural gas.

Table 9. Natural gas use in California industry (Mtherms)[56]

Sector	2016	2017	2018	2019	2020
Oil and gas extraction	3281	3223	3166	3108	3051
Petroleum refining	880	876	872	868	864
Food and beverage processing[xvi]	710	703	700	694	684
Chemical manufacturing	665	662	664	664	662
Glass	568	559	555	547	536
Cement	221	223	224	224	221

HYDROGEN

Compared to electrification, low-carbon hydrogen is a higher-cost decarbonization fuel best reserved for the GHG sources that are hardest to decarbonize. Hydrogen is expected to be a growing source of lower-carbon energy for some industries with extreme heat demands.[57] Hydrogen is a flammable gas, emitting no CO_2 when it burns. This makes hydrogen different from fossil fuels like natural gas and petroleum, whose combustion accounts for the vast majority of GHG emissions today. The carbon intensity of hydrogen depends on how the hydrogen is made. Today, most hydrogen is produced using fossil fuels.

Hydrogen made using electrolyzers and electrical energy has the potential to be very low in carbon, but it is now prohibitively expensive in most cases. The California EPS assumes grid-connected electrolysis as the hydrogen production method, which incorporates a learning curve for electrolyzers bringing down cost over time. Still, even accounting for battery replacement every seven years in electric heavy-duty freight trucks, the equivalent hydrogen fuel cell ownership cost remains more expensive through 2050. Industry is the only sector with significant hydrogen use in the Deeper Decarbonization Scenario.

CARBON PRICING

Carbon prices always carry political challenges due to potential consumer price effects, though revenue use can offset affordability concerns and even contribute to more equitable public investment. Today, historic inflation rates raise additional political hurdles for pricing policies. Political feasibility is the primary consideration for not modeling higher-than-expected future carbon prices as part of the Deeper Decarbonization Scenario.

The effectiveness of the state's cap-and-trade program, which technically operates under the aegis of the Western Climate Initiative through a carbon market fully linked with the Canadian Province of Quebec, faces challenges due to the emergence of an oversupply of tradable permits and continued free allocation.

Oversupply refers to the surplus of carbon allowances, i.e., tradable emissions permits, held by private enterprises. Oversupply leads to lower future carbon prices, all else equal, based on simple supply-demand

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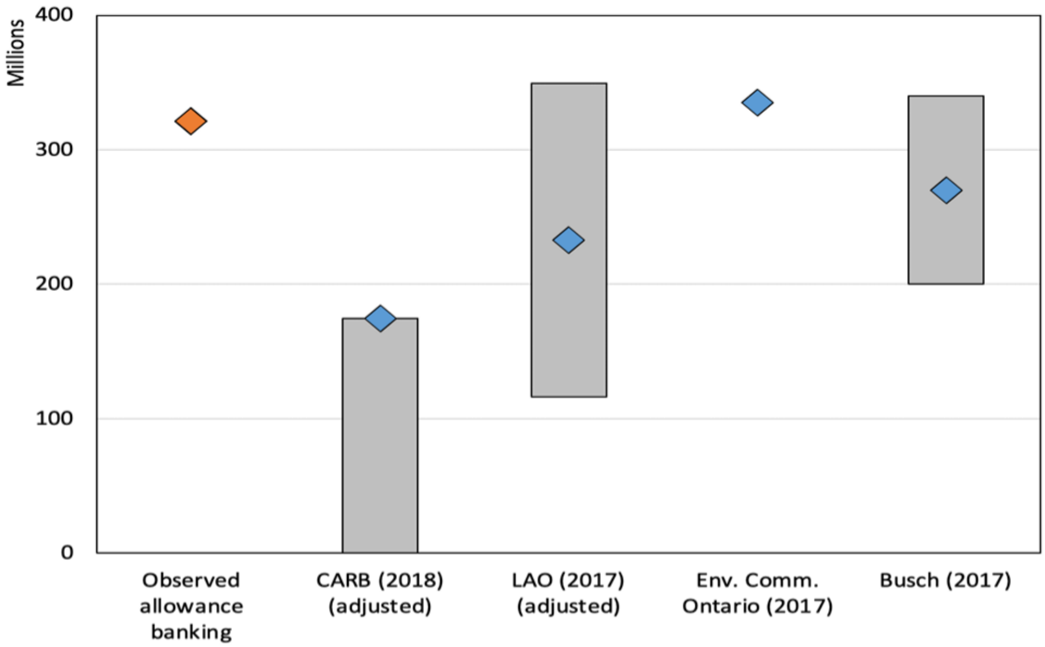
[xvi] These data combine the PATHWAYS model subsector categories "food & beverage" and "food processing."

dynamics. The Independent Emissions Market Advisory Committee recently found that the private bank of allowances has grown to exceed 300 million tonnes.[58] Figure 23 cites earlier Energy Innovation work—Busch (2017)—along with three analyses raising concerns about the effect of accumulating surplus carbon allowance permits.[59]

Figure 23. Comparison of allowance banking scenarios[60]



Future cap-and-trade program design will have to grapple with oversupply, along with mounting evidence that free allocation undercuts carbon pricing's effectiveness. In 2016, AB 398 shocked more than a few people in beating the two-thirds supermajority threshold in both the state Assembly and Senate. A provision in AB 398 specifically prohibited the stepping down of free allocation to industry, as had been planned.

To understand why free allocation inevitably distorts the carbon price, consider that even using best practices, free allocation in a cap-and-trade program is linked to levels of production. Thus, free allocation provides a production subsidy of sorts, distorting the price signal. The effect of this can be seen clearly in the IEA's study of China's national emission trading system, finding that introducing auctioning would lead to greater fuel switching and faster emissions reductions than current plans.[61] For another example, an EU-commissioned study concludes that free allocation inevitably weakens the price signal for long-term, large investments, stating: "Summarizing the findings in literature, it can be concluded that free allocation does distort the CO_2 price signal to some extent, despite the theoretical independence between allocation method and abatement behavior."[62]

CONCLUSION

At a time of spiking fossil fuel prices and comparatively stable electricity rates, California EPS results spotlight electrification's advantages. Accelerated electrification of cars and light trucks, which is expected with stronger zero-emission sales requirements, provides both large emissions reductions and cost savings. Phasing out fossil fuels and replacing them with affordable clean energy can help California build a stronger, fairer economy. Ambitious policies will spur innovation and entrepreneurialism in the clean technologies increasingly in demand worldwide. California residents will benefit from cleaner air, cities offering better quality of life, and improved health. Several important co-benefits are beyond the scope of this research, such as improved urban mobility and higher quality of life in cities. Reduced exposure to volatile fossil fuel prices is another co-benefit not reflected in results. Finally, international climate efforts will benefit as California offers both technological innovation and policy inspiration. We hope the new California EPS model will be of service to policymakers and all people engaged in the hard work of shepherding the state's climate strategy.

APPENDIX: TRANSPORTATION FUEL AND VEHICLE PRICES

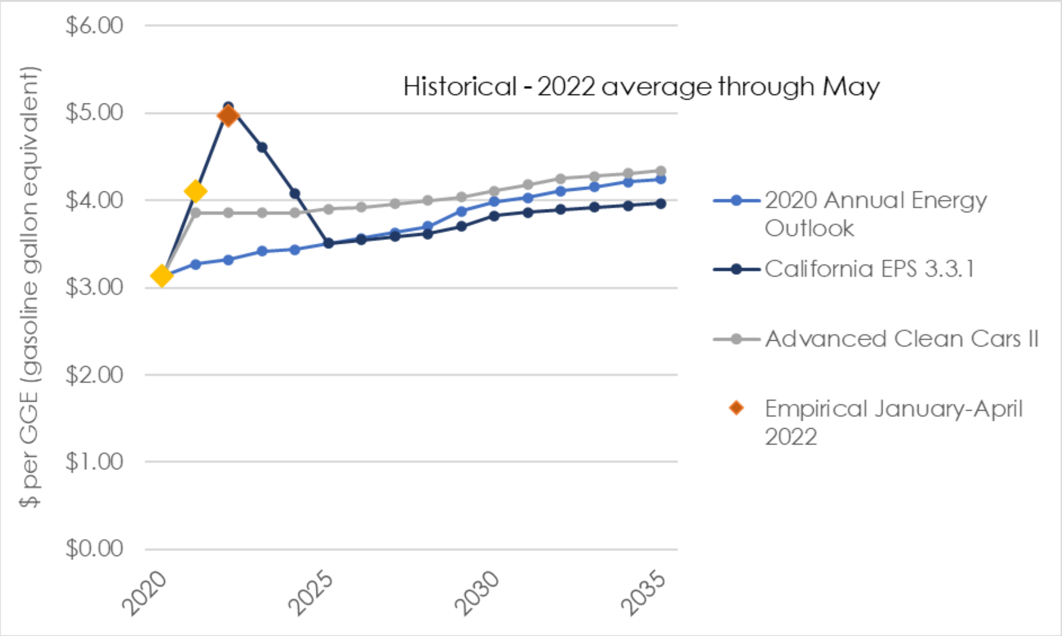
This appendix documents BAU Scenario fuel prices and motor vehicle purchase prices in the California EPS 3.3.1. These are key determinants of EV policy cost effectiveness.

First, we address fuel prices, including comparison to fuel price trends in the analysis released with the 2022 Scoping Plan as well as the Advanced Clean Cars II analysis. CARB's Advanced Clean Cars II rulemaking is currently considering a staff proposal to reach the threshold of 100 percent zero-emission car and light truck sales by 2035.[63] The state's ZEV sales requirement has a history dating back to 1990, when CARB first adopted the rule purely as a smog-fighting tool. Decades later, as this research shows, ZEVs are a leading climate solution in transportation, with EVs expected to be the preferred technology.

California's ZEV sales standard has always been technologically neutral, with eligibility based on vehicle performance, i.e., whether it meets the criteria of eliminating emissions directly related to vehicle operation. EVs are expected to be the dominate decarbonization for on-road transportation. Hydrogen fuel cell vehicles also qualify as a ZEV technology but are a more expensive option, according to the California EPS and other research.[64]

Analysis supporting Advanced Clean Cars II draws gasoline and diesel prices from the California Energy Commission's 2021 Integrated Energy Policy Report mid-demand projection. Scoping Plan analysis cites the 2020 Annual Energy Outlook to forecast transportation fuel prices but does not specify the start year price. Figure 24 calculates the 2020 Annual Outlook Price path based on the California historical 2020 retail gasoline price and uses the AEO's year-over-year percentage changes to impute values in future years, as expected for the Scoping Plan analysis, though its documentation leaves room for interpretation.

Figure 24. Gasoline price paths in EPS, Advanced Clean Cars II, and Scoping Plan modeling



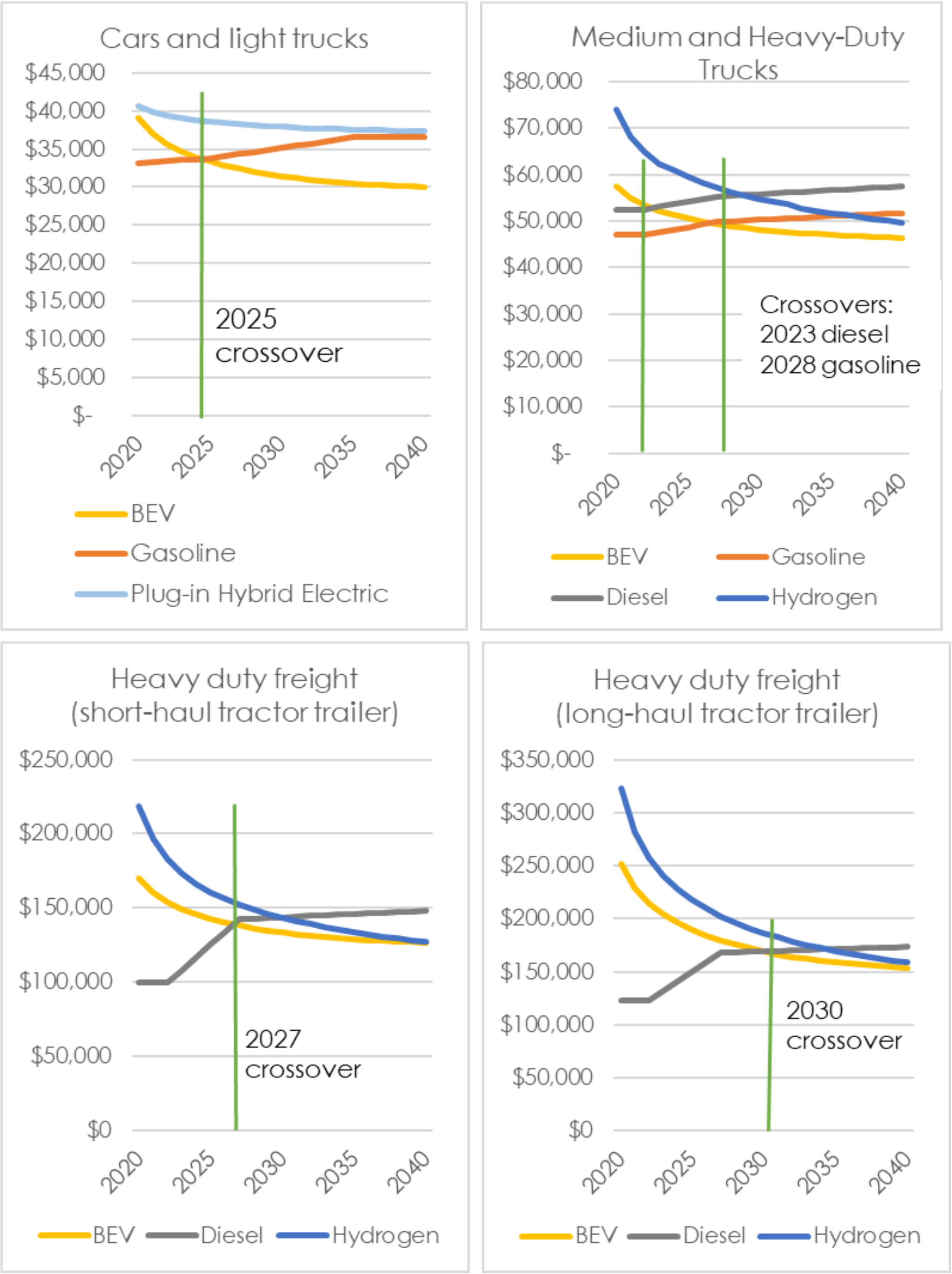
There is a risk in reading too much into the divergence in fuel price in the early years of these different analyses because most policy impacts occur after 2025, when the effect of using the SEO to capture the effect of current petroleum fuel price spikes is no longer relevant.[xvii] The similarity between the California EPS and other analyses is evidenced by the fact that ZEV policies are the most economically advantageous policies found in the analysis for the Draft 2022 Scoping Plan.

The following graphs show new vehicle prices in the EPS Deeper Decarbonization Scenario. EPS prices account for battery learning curves, which explain the downward trend in EV price. The modestly rising price for new gasoline and diesel vehicles reflects expected higher costs to comply with more stringent clean air requirements. Purchase price trends graphed next indicate that EVs reach cost competitiveness between 2025 and 2030 across a range of classes of cars and trucks.

Figure 25 shows the average battery-electric car and light truck purchase price is expected to fall to become cost competitive with internal combustion engine vehicles by mid-decade, eventually saving consumers roughly $1,700 in 2030. Hence, purchase price parity for EVs is expected to be a waystation, not a destination, on the way to EVs achieving an up-front cost advantage.

[xvii] The Data subsection under Methodology outlines the EPS's approach to BAU fuel prices, which combines EIA SEO and AEO forecasts.

Figure 25. New vehicle price and crossover years for different vehicle types[xviii]



[xviii] Vehicle prices discussed in this Appendix do not account for consumer incentive effects. Figure 23 results reflect policy calibration in the Deeper Decarbonization Scenario. This is notable because vehicle prices are affected by EV and vehicle efficiency policy calibration: in modeling terminology, the EPS determines new vehicle prices endogenously. Policies speeding EV deployment cause faster progress up the battery learning curve, lowering EV prices (though these effects are stronger and more evident in larger new vehicle markets captured in EPS models for the U.S. or China). The EPS also accounts for policy-induced additional vehicle efficiency in internal combustion engine vehicles.

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