Exhibit B

Effectiveness and Cost-Effectiveness of Alternative SORE Emission Standards

Truck & Engine Manufacturers Association

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Contents

Table of Tables

Table of Figures

Executive Summary

A. Study Objectives

This report evaluates the effectiveness and cost-effectiveness of alternative Small Off-Road Engine ("SORE") standards for non-handheld equipment subject to regulation by the California Air Resources Board ("CARB"). The evaluations are based upon a detailed database developed from a survey of four engine manufacturers that account for the vast majority of non-handheld engine sales in California. The database includes information on baseline (i.e., current) engine emissions and sales as well as the costs and emission reductions associated with specific emission-control technologies. This detailed database is used to determine the cost-minimizing compliance strategy a company would pursue under three alternative proposals for SORE emissions standards for an illustrative model-year when full implementation of each alternative standard is required.

(a) *EMA proposal ("EMA Proposal")*. Proposal of the Truck and Engine Manufacturers Association ("EMA") to require zero emission equipment ("ZEE") as substitute for conventional engines in walk-behind lawnmowers and cost-effective controls on all other engines.

(b) *EMA proposal and CARB Staff Interim Evaporative Standards ("EMA & Staff Interim Evap Proposal")*. Addition of the CARB staff interim evaporative emission standards to the EMA Proposal.

(c) *CARB Staff Final ZEE Proposal ("Staff ZEE Proposal")*. Proposal of the CARB staff ("Staff") to require zero emission equipment ("ZEE") as substitutes for all non-handheld engines as the final standards for all SORE equipment.

The compliance results are then used to calculate aggregate effectiveness (i.e., lifetime emissions reductions from the baseline) and incremental cost-effectiveness (i.e., the cost-per-ton of the additional emissions reductions) for the three alternative proposals.

We base these assessments on two types of economic analyses: (1) economic analyses that ignore market price effects; and (2) economic analyses that include market price effects. Market price effects take into account the fact that more expensive emission control requirements will lead to higher prices for new equipment, resulting in both reduced scrappage of existing equipment ("scrappage effect") and shifts in sales to neighboring states where CARB regulations do not apply ("leakage effect"). Both of these well-established effects lead to emissions *increases* that offset the emissions reductions expected from more stringent standards for new equipment. As noted below, for the Staff ZEE Proposal, these increases more than offset the emissions reductions from the ZEE standards, resulting in the Staff ZEE Proposal actually causing California emissions to increase relative to the reductions that would occur if either of the other two proposals were adopted.

As an adjunct to the NERA-Trinity cost-effectiveness analyses, this report comments on the limited set of alternatives included in the economic analyses in the Standardized Regulatory Impact Analysis ("SRIA") and Initial Statement of Reasons ("ISOR") provided by CARB staff. In contrast to the NERA-Trinity study—which includes standards representing a wide range of final stringency—the alternatives considered by the Staff all assume that ZEE is required to replace all SORE engines, with differences in the timing within a narrow four-year window from model year 2024 to model year 2028.

B. Effectiveness and Cost-Effectiveness Results Excluding Market Effects

Figure ES-1 shows estimates of the overall effectiveness and the *incremental* cost-effectiveness of the three alternative SORE standards, excluding market impacts. The following are key comparisons of effectiveness, i.e., emission reductions relative to baseline emissions over time for the given model year.

- The EMA Proposal reduces model year emissions by 62 percent. The figure also shows that applying a ZEE requirement to walk-behind lawnmowers alone reduces model year emissions by 25 percent.

- The EMA & Staff Interim Evap Proposal reduces model year emissions by another five percent, resulting in a total reduction of 67 percent.

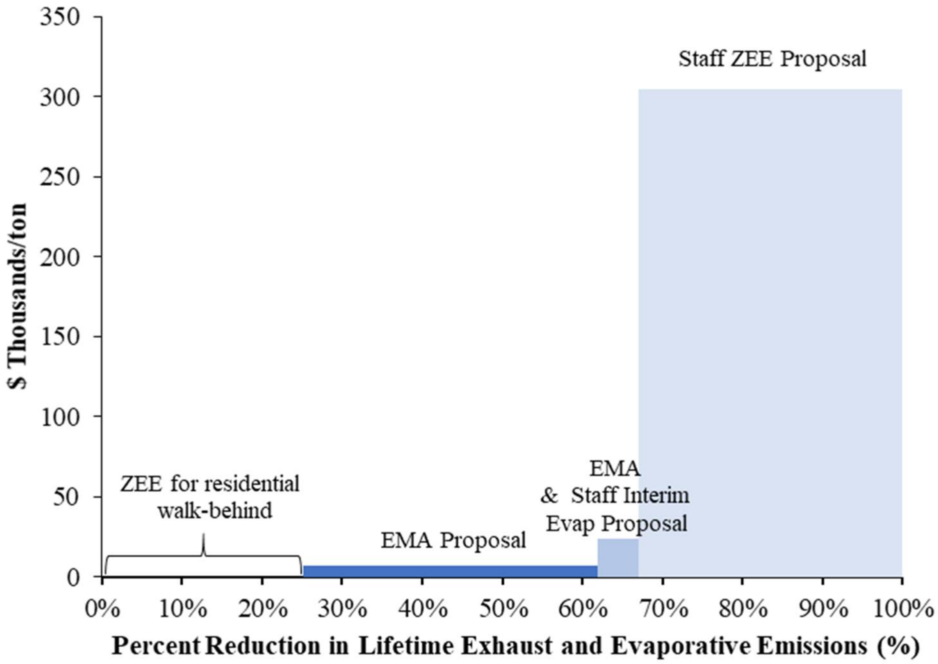
- The Staff ZEE Proposal reduces model year emissions by another 33 percent, resulting in a total reduction of 100 percent, as expected.

Figure ES-1 shows that the greater effectiveness of the more stringent standards come at increased additional costs per ton, with the cost per additional ton of emissions eliminated being particularly large for the Staff ZEE Proposal. The following is a summary of these incremental cost-effectiveness results.

- The EMA Proposal achieves its 62 percent reduction at an average cost of about $7,000 per ton of emissions eliminated.
- The EMA & Staff Interim Evap Proposal achieves its additional five percent reduction at a cost of about $16,700 per additional ton.
- The Staff ZEE Proposal achieves its additional 33 percent reduction at a cost of about $304,100 per additional ton.

These results mean that even excluding the market effects due to higher new equipment prices, the additional emission reductions from the Staff ZEE Proposal are dramatically more expensive than the tons achieved by the other two proposals—more than 18 times as expensive as the EMA & Staff Interim Evap Proposal and more than 43 times as expensive as the EMA Proposal. Again, these results ignore the offsetting impact of market price effects on emissions. As shown below, proper accounting for market effects substantially reduces the effectiveness of the Staff ZEE Proposal, resulting in *net* emissions reductions that are *smaller* than for either of the other two proposals.

Figure ES-1: Effectiveness and Cost-Effectiveness of Three Sets of SORE Standards, Excluding Market Impacts



Source: Calculations as explained in text.

C. Effectiveness and Cost-Effectiveness Results Including Market Effects

The results in section B exclude the market effects of higher new equipment prices, i.e., the effects of the standards on equipment prices and thus on California equipment sales, resulting in offsetting emissions increases. The offsetting emissions increases are based upon two market effects: (1) a scrappage effect that reflects some consumers deciding to keep their existing equipment longer rather than buying the more-expensive new equipment; and (2) a leakage effect that reflects some consumers deciding to buy new equipment outside California (e.g., Nevada) to avoid the more expensive new equipment in California. NERA developed empirical estimates of these well-established market impacts of more expensive controls on new equipment (and thus higher prices for new equipment in California).

Figure ES-2 shows the results of these empirical estimates, with the same format as in Figure ES-1 but with the results modified to reflect the reduced tons due to the scrappage and leakage effects. Effectiveness estimates are provided for all three proposals and are summarized as follows.

- The EMA Proposal reduces emissions by 60 percent when market effects are included, down slightly from the 62 percent reduction ignoring market effects.

- The EMA & Staff Interim Evap Proposal reduces emissions 64 percent when market effects are included, three percentage points down from the 67 percent reduction ignoring market effects

- The Staff ZEE Proposal reduces emissions by 49 percent when market effects are included, i.e., a *smaller* net reduction than the other two proposals (11 percentage points less than the EMA Proposal and 15 percentage points less than the EMA Proposal & Staff Interim Evap Proposal) and of course dramatically lower than the 100 percent reduction for the Staff ZEE Proposal when market impacts are ignored.

These reduced effectiveness estimates in Figure ES-2 result in changes in the cost-effectiveness estimates, but only two results can be shown on the graph because, as noted, the Staff ZEE Proposal leads to negative incremental effectiveness, i.e., emissions reductions are smaller than those obtained with the other two alternatives.

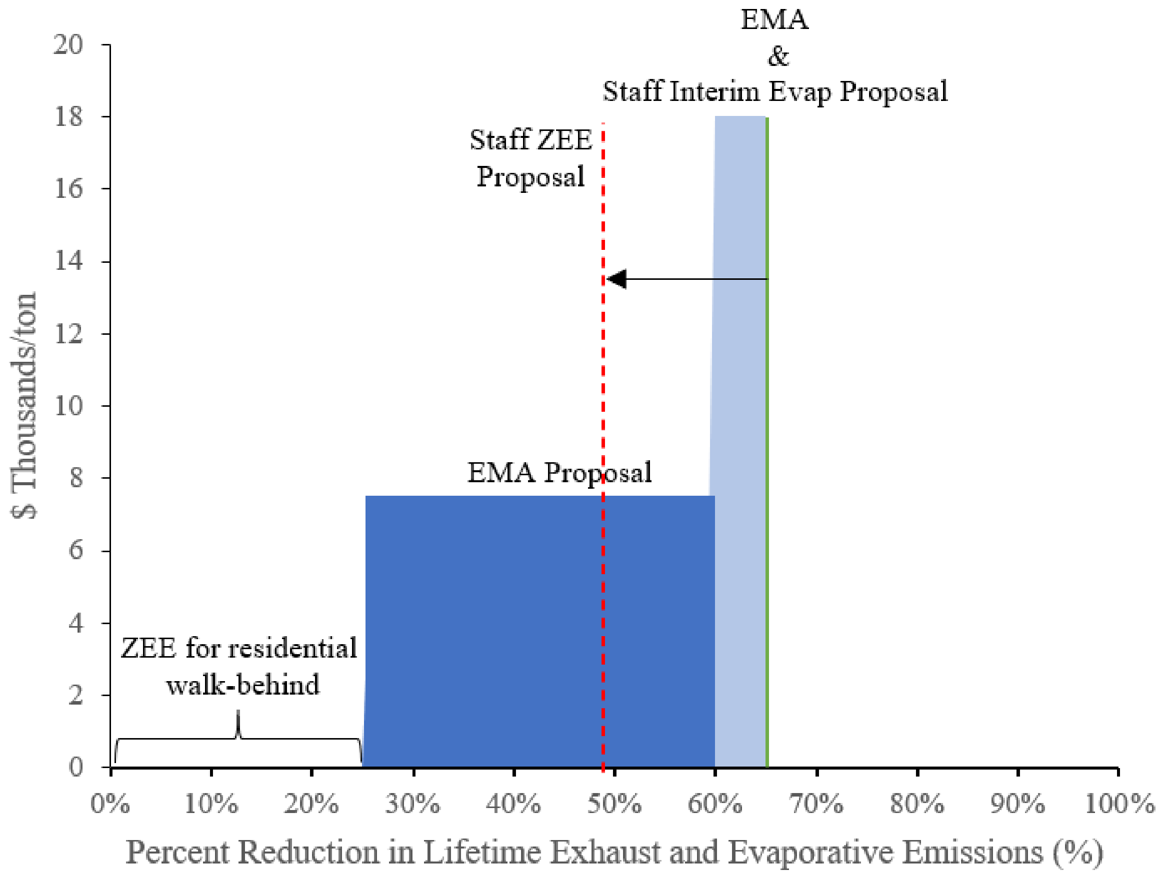
- The EMA Proposal achieves its 60 percent reduction at an average cost of about $7,500 per ton, up somewhat from the about $7,000 per ton when market effects are excluded.

- The EMA & CARB Interim Evap Proposal achieves its additional four percent reduction at a cost of about $17,700 per additional ton, up somewhat from the about $16,700 per ton when market effects are excluded.

- Because the Staff ZEE Proposal leads to lower emissions reductions than the other alternatives, its incremental cost-effectiveness is negative and cannot be meaningfully shown on the figure.

These results indicate that the Staff ZEE Proposal is clearly inferior to the other two proposals when market impacts are included, as both of the other proposals lead to greater emissions reductions at substantially lower cost. Put another way, because of the market effects, the Staff ZEE Proposal would work against CARB's goal of reducing SORE emissions in comparison to either the EMA Proposal or the EMA Proposal & Staff Interim Evap Proposal.

Figure ES-2: Effectiveness and Cost-Effectiveness of Three Sets of SORE Standards, Including Market Impacts



Source: Calculations as explained in text.

D. Limitations of the Alternatives Considered in the Staff Economic Analyses

The regulatory alternatives evaluated in this report represent a substantial range of potential stringency. In contrast, the Staff ISOR and SRIA does not provide information on alternatives that differ in their final stringency. All of the alternatives evaluated by CARB staff presume that ZEE standards will be required both for exhaust and evaporative emissions for all SORE equipment with the only difference among alternatives being the timing of implementation (ranging from the 2024 model year to the 2028 model year).

Evaluating alternatives with a range of stringency is recommended by economists and policy analysts to provide decision makers with full information on the choices before them, and for good reason. The lack of alternatives that differ in final stringency deprives the CARB of important information as they decide on SORE standards.

E. Conclusions

The following are the two principal conclusions of our study of the effectiveness and cost-effectiveness of three alternative sets of SORE emission standards (EMA Proposal, EMA Proposal & Staff Interim Evap Proposal, and Staff ZEE Proposal).

- Even ignoring market price effects, the Staff ZEE Proposal is dramatically less cost-effective than the two less stringent alternatives, with the additional tons that are reduced due to the Staff ZEE Proposal costing more than $300,000 per additional ton.

- When market price effects are included, the Staff ZEE Proposal is clearly inferior to the other two proposals, as both of the other proposals would yield greater emission reductions at dramatically lower costs.

The Staff economic analyses in the SRIA and ISOR are severely limited by their failure to evaluate a range of standards that differ in final stringency, as the Staff ZEE Proposal and all alternatives assume eventual ZEE standards for all SORE equipment. The lack of a wide range of alternative stringencies—that allow for estimates of the incremental costs and benefits of increasingly stringent final standards—means that the Staff have not provided the Board or the public with important economic information on potential alternative SORE standards.

1. Introduction

A. Background on Staff ZEE Proposal

This section provides background on the Staff ZEE proposal, including the prior proposals presented to stakeholders by the Staff.

1. June 2020 Staff Workshop

In June 2020, Staff hosted a public workshop to discuss potential changes to CARB's SORE emission regulations. The proposed changes included interim changes to the regulations beginning in model year 2023 that included increased stringency in exhaust emissions standards, increased equipment durability periods, and new measures and testing of evaporative emissions standards. The proposed amendments also set 2025 emissions standards to zero and banned the sale of combustion engine equipment beginning in 2028 at which time all SORE engines would be replaced by ZEE. Table 1 shows the proposed changes to exhaust emissions standards.

Table 1: Staff June 2020 Proposed SORE Exhaust Emissions Standards (g HC + NOx/kWh)

	Standard	
Period	**Class I**	**Class II**
Current	10.0	8.0
Interim, 2023-2024	6.0	3.0
Final, 2025+	0.0	0.0

Source: CARB 2020

Table 2 shows the proposed changes to evaporative emissions standards. The proposed future standards include a new hot soak test that adds the emissions resulting from leaving the engine in a 95 degree Fahrenheit room for an hour before directly continuing with the diurnal test for total evaporative emissions.

Table 2: Staff June 2020 Proposed SORE Evaporative Emissions Standards

Period	Class I, Walk-Behind	Class I, Other	Class II
Current (Diurnal, g HC/day)	1.00	0.95+0.056*tank size	1.20+0.056*tank size
Interim, 2023-2024 (Diurnal + Hot Soak, g HC/test)	0.60	0.60	0.70
Final, 2025+ (Diurnal + Hot Soak, g HC/test)	0.00	0.00	0.00

Source: CARB 2020

Table 3 shows the proposed changes in durability periods. Current durability periods are based on the intended final use (residential, heavy residential, or commercial). CARB's proposed durability standards are uniform across all potential final uses.

Table 3: Staff June 2020 SORE Engine Durability Periods (hours)

	Standard	
Period	**Class I**	**Class II**
Current	125/250/500	125/250/500/1000
Interim, 2023-2024	2,000	5,000
Final, 2025+	2,000	5,000

Source: CARB 2020

2. March 2021 Staff Workshop

In March 2021, CARB hosted another workshop to announce changes to the proposed regulations. An accelerated ZEE requirement by model year 2024 replaced the interim exhaust and evaporative emissions standards for all equipment with the exception of generators, for which the ZEE requirement would begin in model year 2028.

CARB also decreased the durability period requirements in response to comments that the durability periods proposed in June 2020 were not feasible. The new durability periods would reflect the maximum values currently certified in Class I and Class II engines, i.e., 500 hours for Class I and 1,000 hours for Class II. (CARB 2021a)

3. Final Staff Proposed SORE Standards

The final Staff proposed SORE Standards reflect the same ZEE requirements for all equipment, with the exception of generators, as in the March 2021 Staff Workshop. For generators, the standards would increase in stringency for 2024-2027 before the ZEE requirement extends to generators in 2028. Table 4 and Table 5 summarize the Staff Proposed Standards for generators, which are allowed a longer time period to meet the final ZEE requirements. But the most important feature of the Staff proposed standards is that all SORE equipment would face ZEE requirements beginning in model year 2028.

Table 4: Final Staff Proposed SORE Exhaust Emissions Standards) for Generators (g HC+NOx/kWh)

Period	Class I Generators	Class II Generators
Current	10.0	8.0
Interim, 2024-2027	6.0	3.0
Final, 2028+	0.0	0.0

Source: CARB 2021c

Table 5: Final Staff Proposed SORE Evaporative Emissions Standards for Generators

Period	Class I Generators	Class II Generators
Current (Diurnal, g HC/day)	1.20+0.056*tank size	1.20+0.056*tank size
Interim, 2024-2027 (Diurnal + Hot Soak, g HC/test)	0.60	0.70
Final, 2028+ (Diurnal + Hot Soak, g HC/test)	0.00	0.00

Source: CARB 2021c

B. Objectives of this Study

This report evaluates the effectiveness and cost-effectiveness of alternative SORE standards. The evaluations are based upon a detailed database developed from a survey of four engine manufacturers that account for the vast majority of non-handheld equipment sales in California. This detailed database is used to model companies' cost-minimizing compliance with three alternative SORE emissions standard proposals.

(a) *EMA proposal ("EMA Proposal")*. Proposal of the Truck and Engine Manufactures Association ("EMA") to require zero emission equipment ("ZEE") for walk-behind lawnmower engines and cost-effective controls involving a 60 percent reduction in standards for all other engines.

(b) *EMA proposal & Staff Interim Evaporative Standards ("EMA & Staff Interim Evap Proposal")*. Addition of the Staff interim evaporative emission standards to the EMA Proposal.

(c) *Staff ZEE Final Proposal ("Staff ZEE Proposal")*. Proposal of the Staff to require ZEE for all non-handheld engines.

Using the detailed engine database, we model the cost-minimizing compliance solution for each manufacturer (assuming use of emissions averaging) for the three sets of standards for a given model year. Based on the technology controls selected in the compliance solution, we estimate the lifetime emissions reductions and the compliance costs (i.e., costs to modify engines and equipment to achieve the standards, based upon the potential categories listed in the survey in Appendix A) of the three proposals, taking into account estimated fuel savings from electric rather than gasoline equipment. Social costs (i.e., costs to society) for a given standard for the model year production include the relevant compliance costs as well as the estimated lifetime fuel savings.

With these results for each set of standards, we calculate the effectiveness and *incremental* cost-effectiveness of the increasingly stringent sets of standards. That is, we calculate the additional cost per additional ton of emissions reduction for the three increments (i.e., from baseline to EMA Proposal, from EMA Proposal to EMA & Staff Interim Evap Proposal, and from EMA & Staff Interim Evap Proposal to Staff ZEE Proposal). As noted below, we also consider the implications of market changes (due to increases in new equipment prices) for social costs and lifetime emissions reductions and modify these estimates, developing revised calculations of effectiveness and cost-effectiveness for the three sets of standards that include market effects.

C. Organization of the Report

The remainder of the report is organized as follows. Section II describes the data and methodology used in the effectiveness and cost-effectiveness analyses. Section III presents the results of the effectiveness and cost-effectiveness analyses for the three SORE proposals, *excluding* market effects. Section IV presents the results of the effectiveness and cost-effectiveness analysis for the three SORE proposals, *including* market effects. Section V discusses the limitations of the alternatives considered in the Staff economic analyses in the ISOR and SRIA. Section VI provides brief conclusions. Appendix A provides information on the survey used to develop the detailed costs and emissions data.

II. Effectiveness and Incremental Cost-Effectiveness Methodology

This section provides an overview of the methodology we use to develop estimates of the effectiveness and the incremental cost-effectiveness of the three proposals. We include information on the methodology used to develop estimates of effectiveness and cost-effectiveness both with and without incorporation of market effects.

A. Overview of Methodology for Effectiveness and Cost-Effectiveness Analyses

The following are the basic empirical steps to develop estimates of the effectiveness and the incremental cost-effectiveness of the three proposals. As noted, these steps relate to estimates without market effects as well as estimates with market effects.

- Develop detailed engine database for each manufacturer.
- Specify the three alternative proposals, i.e., sets of SORE emission standards.
- Develop estimates of the technologies that would be chosen for each of the manufacturers to comply with the three sets of standards for the model year where final implementation of the standards is required.
- Develop estimates of social costs and lifetime emission reductions for each proposal, ignoring market impacts.
- Use the two sets of estimates (social costs and lifetime emissions) to calculate the effectiveness (i.e., total emissions reductions) and incremental cost-effectiveness of the three proposals, without market effects.
- Develop estimates of changes in new equipment prices and use a demand elasticity estimate to estimate reductions in new equipment sales.
- Develop estimates of offsetting increases in emissions due to market changes, i.e., increases in use of existing SORE equipment (i.e., lower scrappage) and leakage of new equipment sales to other states (e.g., Nevada).
- Calculate social costs of each proposal incorporating market effects, which include (a) the original social costs assuming sales are not affected, (b) the reductions in costs due to reduced new equipment sales and (c) the offsetting increases in social costs (consumer surplus loss) due to reduced new equipment sales.
- Use the two sets of estimates (social costs and lifetime emissions) to calculate the effectiveness (i.e., net emissions reductions) and incremental cost-effectiveness of the three proposals, with market effects.

Following sections provide information on the data and methodology related to elements of these various empirical steps.

B. Development of Detailed Engine Database

We developed a detailed survey to obtain cost and emissions data for this study. Appendix A provides the specific elements of the survey. The survey developed data on the costs and emissions rates associated with incorporation of exhaust and evaporative emissions control technologies, including a switch to battery electric. Engineers and other technical personnel at the four participating manufacturers completed the surveys.

1. Engine Family Baseline Data

Following an extensive review process, during which the data were verified and checked for internal consistency, we developed a detailed engine-specific database that includes the following baseline information for each engine family:

- 2024 Projected sales volumes
- Power
- End-use application
- Exhaust emission rate and engine durability period
- Evaporative emissions rate of end-use equipment

Manufacturers grouped engines by the following ten equipment types.

Table 6: Equipment Types

Class	Equipment
I	Residential Walk Behind Mower
I	Commerical Walk Behind Mower
I	Pressure Washer
I	Portable Generator Class I
I	Construction/Utility Class I
II	Portable Generator Class II
II	L/G Tractor
II	ZTR Commercial
II	ZTR Residential
II	Construction/Utility Class II

2. Emission Control Technologies

For each application, the manufacturers could provide up to three control options to reduce exhaust emissions. For each exhaust emissions control technology, manufacturers provided the following information:

- Exhaust emissions rate reduction
- Evaporative emissions rate reduction (if any)
- Control technology costs (including capital costs and variable costs)

In addition to any reductions in evaporative emissions from controls to reduce exhaust emissions (e.g., reductions in evaporative emissions from switching to Electronic Fuel Injection or "EFI"), manufacturers could provide three control options for evaporative emissions. For each evaporative emissions control, manufacturers provided the following information:

- Evaporative emissions rate reductions
- Control technology costs (including capital costs and variable costs)

This approach allows for interactions between exhaust controls and evaporative controls in that evaporative emissions rate reductions could depend on the application of exhaust controls. For example, engine modifications to reduce evaporative emissions could affect the evaporative emissions rate differently depending on whether the engine family has or has not switched to an EFI system.

As noted, the survey instrument used to develop the detailed database is provided in Appendix A.

3. Lifetime Emissions Reductions of Control Technologies

Based on the effectiveness information provided in the survey, Trinity modeled the lifetime emissions of current (baseline) engines as well as engines with emissions control technologies. These estimates account for deterioration over the certified useful life of the equipment and for characteristics of the engines (e.g., in-use load factors and max engine power).

C. Proposals for Alternative Sets of SORE Standards

As noted in the introduction, this study evaluates incremental cost-effectiveness for three sets of standards.

1. EMA Proposal.
2. EMA & Staff Interim Evap Proposal.
3. Staff ZEE Proposal.

The following subsections provide information on these three sets of SORE emission standards.

a. EMA Proposal

The EMA Proposal has three key components: (a) a ZEE requirement for residential walk-behind lawnmower; (b) a sixty percent reduction in exhaust standards for equipment other than residential walk-behind mowers, based upon cost-effective considerations; and (c) an increase in durability periods to the current maximum durability of each engine class.

i. ZEE Requirement for Residential Walk-Behind Mowers

The EMA Proposal provides for a ZEE requirement for residential walk-behind mowers. This provision is not based upon cost-effectiveness considerations but rather on an understanding that electrifying this equipment category is technically feasible and allows for achievement of basic consumer requirements. Note that the ZEE requirement for residential walk-behind mowers is not included in the cost-effectiveness analysis of the EMA Proposal. Moreover, because we focus on the incremental cost-effectiveness of the three proposals, information on residential walk-behind mowers also is not included in the cost-effectiveness analysis of the two other proposals.

ii. Sixty Percent Reduction in Exhaust Standards for Other SORE Equipment

NERA and Trinity developed an initial evaluation of the incremental cost-effectiveness for exhaust emissions reductions for all engines in the database. The results of that evaluation show that the incremental cost-per-ton increases substantially after 60 percent of emissions reductions have been achieved. Thus, the EMA Proposal includes a 60 percent reduction in exhaust emission standards for equipment other than residential walk-behind mowers.

iii. Increase in Durability Periods

To accommodate Staff's objective of consolidating durability periods, the EMA proposal increases durability periods to the current limits in each class, i.e., 500 hours for Class I engines and 1,000 hours for Class II engines.

b. CARB Staff Interim Evaporative Emissions Standards

In the 2020 workshop, CARB's draft changes to SORE standards included significant modifications of evaporative standards, including the measurement of evaporative emissions, the testing of evaporative emissions rates, and the stringency of the standards. Table 7 summarizes the evaporative standards. The proposed standards combine the 24-hour diurnal emissions (g HC per day) with hot soak emissions measured in a one-hour test (g HC per test). The new evaporative standards also removed the standards' dependence on engines' fuel tank size and consolidated Class I engines under a single standard (rather than separate Class I standards for residential walk-behind mowers and other Class I engines).

Table 7: California CARB Staff 2020 Draft SORE Regulation Changes in Evaporative Emissions Standards

Period	Class I	Class II
Current (Diurnal, g HC/day)	0.95+0.056*tank size	1.20+0.056*tank size
Interim, 2023-2024 (Diurnal + Hot Soak, g HC/test)	0.60	0.70
Final, 2025+ (Diurnal + Hot Soak, g HC/test)	0.00	0.00

Source: CARB 2020

c. CARB Staff Final ZEE Standards

The ISOR and SRIA provide the proposed ZEE standards for engines to take effect by model year 2024, with the ZEE standards for generators delayed to model year 2028. For the purposes of this analysis, which evaluates a single representative model-year, we assume the CARB Staff ZEE standards apply to all equipment.

d. Summary of Alternative SORE Emissions Proposals

Table 8 and Table 9 summarize the alternative sets of SORE emissions standards included in the economic assessments. In addition to the changes in exhaust and evaporative emission rates shown, each of the three alternative sets of standards also sets the durability periods of combustion engines to the current maximum value for each class, i.e., 500 hours for Class I engines and 1,000 hours for Class II engines.

Table 8: Alternative SORE Exhaust Emissions Standards (g HC + NOX/kWh)

Proposal	Res WBM	Class I	Class II
Baseline	10.0	10.0	8.0
EMA	0.0	6.0	3.0
EMA & Staff Interim Evap	0.0	6.0	3.0
Staff ZEE	0.0	0.0	0.0

Table 9: Alternative SORE Evaporative Emissions Standards

Standard	Res WBM	Class I	Class II
Baseline	1.00 g HC/day	.95+0.056*tank size g HC/day	1.20+0.056*tank size g HC/day
EMA	0.0 g HC/test	.95+0.056*tank size g HC/day	1.20+0.056*tank size g HC/day
EMA & Staff Interim Evap	0.0 g HC/test	0.60 g HC/test	0.70 g HC/test
Staff ZEE	0.0 g HC/test	0.0 g HC/test	0.0 g HC/test

D. Determination of Company Compliance with Alternative Sets of SORE Standards

All proposed standards in this study allow for averaging, which means that manufacturers have the flexibility to meet a given set of emission standards in the least-cost means. To estimate each manufacturer’s compliance strategy, we developed a mathematical model to select the least-cost means for each manufacturer to comply with both the exhaust and evaporative standards. We aggregated the results for the four manufacturers to obtain estimates for all engines.

1. Manufacturer Compliance with Exhaust Standard

Equation 1 shows the equation used to calculate the average exhaust emission compliance level for a given manufacturer based upon the family emission level ("FEL") and information on the various engine families.

$$\frac{\sum_{j=1}^{n}(FEL_j)\left(Sales_j Power_j\right)(Load\ Factor)\left(Durability_j\right)}{\sum_{j=1}^{n}\left(Sales_j Power_j\right)(Load\ Factor)\left(Durability_j\right)} = AVG \quad \textbf{(1)}$$

Mathematically, this equation specifies the "weight" that a specific engine family receives in the calculation of fleet average emissions rate for any given suite of installed technologies. Thus, a reduction in the FEL of an engine that has greater sales, has higher rated power, has a longer regulatory lifetime (durability), or is used for a greater number of hours per time period (load factor) contributes more toward compliance than the same reduction in the FEL of an engine that has a smaller value for any of these inputs (other parameters being equal).

2. Manufacturer Compliance with Evaporative Standard

The SORE evaporative standards only weight by production volume. Manufacturers are assumed to comply by maintaining a nonnegative volume of credits in a given year, with credits calculated as in Equation 2 below.

$$Credits = (Applicable\ Standard - EMEL) \times Production\ Volume \quad \textbf{(2)}$$

3. Company Compliance with Proposals

The mathematical model developed to determine the least-cost means of complying with a given set of emission standards finds the technology choices that minimize the joint cost of complying with both sets of standards for the given model year by iterating over alternative technologies. Capital costs are allocated to the single model year based upon assumptions on the number of model years to which the capital costs would apply.

As noted, the mathematical formulation allows for interactions between exhaust and evaporative emission rates. For example, a high marginal abatement cost for exhaust emissions may elicit upgrades to EFI systems or to electric equipment which would contribute to compliance with evaporative emissions standards, thus lowering the marginal abatement cost for evaporative emissions for a fixed evaporative standard.

E. Estimation of Market Impacts of Compliance Costs

1. Categories of Market Impacts

Emissions controls adopted by equipment manufacturers to achieve the three sets of emission standards increase the costs of the modified engines, which in turn increases the prices of new SORE equipment in California. Facing higher equipment prices, some California consumers will change their behavior, either retaining existing equipment rather than buying new equipment (termed the "scrappage effect" because this behavior reduces scrappage rates for existing equipment) or buying the new equipment in a state without the higher prices (termed the "leakage effect" because emissions "leak out" to uncovered sources rather than being reduced on net).

a. Scrappage Effect

Estimating the scrappage effect can be explained as a two-step process. Due to higher new equipment prices, customers retain their equipment as a substitute for purchasing new equipment. As they are using their equipment longer (and there is therefore less scrappage of old equipment), these emissions from the existing equipment offset emissions reductions that would otherwise arise from new lower emissions standards and reduced levels of equipment sales due to higher prices in California.

b. Leakage Effect

The leakage effect likewise results from the increases in new equipment prices in California, with some customers substituting a new equipment purchase in California with a purchase outside California (*e.g.,* Nevada). Non-California purchases due to the leakage effect mean there are no emission reductions arising from these purchases despite the more stringent California standards for new equipment.

The subsections below describe how we estimate the impacts on new sales that could lead to decreased scrappage (i.e., increased retention of old equipment) or increased leakage (i.e., increased purchases of out-of-state equipment).

2. Estimates of Baseline Equipment Prices

Determining the percentage increases in prices due to the three sets of emission standards, it is necessary to estimate baseline equipment prices, i.e., prices without the cost increases due to more stringent emission standards. The baseline prices are based upon representative equipment products for each equipment type from HomeDepot.com in April 2020. The selection was based upon two criteria: first, that the product it is a "Top seller" on HomeDepot.com, and second, that the product has similar power and displacement values to those observed in the database of engines for participating manufacturers. To obtain representative power and displacement values for each equipment type, we calculated sales-weighted averages for power and displacement for engines in the database. Top-selling equipment with comparable values were used to set the baseline price levels for each equipment type. The average prices were rounded to two significant digits. Table 10 shows the resulting estimates of baseline equipment prices.

Table 10: Baseline Equipment Prices

Class	Equipment Assignment	Power (kW)	Displacement (cc)	Price (dollars)
I	Walk Behind Mower	2.6	153.2	$230
I	Pressure Washer	3.7	198.2	$330
I	Portable Generator Class I	3.0	136.4	$2,100
I	Construction/Utility Class I	3.3	157.6	$650
II	Portable Generator Class II	10.2	444.0	$3,400
II	L/G Tractor	14.0	668.8	$1,500
II	ZTR Commercial	17.1	752.2	$6,700
II	ZTR Residential	16.6	726.0	$3,000
II	Construction/Utility Class II	8.8	393.7	$1,000

Source: HomeDepot.com, April 2020; Calculations as explained in text.

3. Estimating "Price" Impacts on California New Equipment Sales and Scrappage/Leakage

a. Calculation of Equipment Price Increase

To estimate the price increases by equipment type relative to the baseline price levels above, we assume the change in equipment price is equal to the change in average equipment cost. For a switch to electric equipment, we calculate the difference between the expected lifetime fuel costs of the combustion-engine equipment and the lifetime electricity costs of the electrified equipment and subtract these cost savings from the control technology costs to estimate the net price impact. Thus, for electrification, the cost increases are net of estimated fuel savings and electricity costs.

$$Price = Price_0 + Technology\ Costs - Fuel\ Savings + Electricity\ Cost \qquad \textbf{(3)}$$

For example, with a per-engine technology cost of $59 and a net reduction in fuel costs of $19, the net price increase would be $40. With a baseline price of $330, the percentage price increase would be about 12 percent.

b. Impacts of Price Increase on New Equipment Sales

To determine the impacts of price increases on California equipment sales, we use the price elasticity of demand of -0.76 based on a prior NERA demand elasticity study.[1] This elasticity indicates that a 1 percent increase in price would lead to a 0.76 percent reduction in equipment sales. We assume this elasticity is constant along the demand curve, as in the functional form in Equation 4 below:

[1] The study is contained in Darlington et. Al (2010).

$$\ln(Sales) = \alpha + \beta \ln(Price) \quad \textbf{(4)}$$

where β is the price elasticity of -0.76.

With this equation, we calculate the estimated new California equipment sales level from a change in price as

$$Sales = e^{\ln Sales_0 - 0.76 \ln \frac{Price}{Price_0}} \quad \textbf{(5)}$$

where $Sales_0$ and $Price_0$ are the baseline sales and prices.

We calculate the sales impacts for each equipment type in aggregate using a sales-weighted average of the net price increases across all engine groups for that equipment type. For example, if baseline pressure washer sales are 56,000 and the baseline average price is $330, an average price increase for a new pressure washer of $40 would be estimated to lead to a decrease in sales of 8 percent, or 5,200 pressure washers in California.

c. Impacts of Market Impacts on Social Costs

The reduction in new equipment sales results in a reduction in compliance costs, which is based on the average compliance costs multiplied by the change in California new equipment sales. But the price increase also reduces consumer surplus (i.e., the value to consumers as reflected in the relevant demand curve). The change in consumer surplus is estimated using the following formula:

$$\Delta Consumer\ Surplus = e^{\frac{\ln Sales_0 - .76 ln Price_0}{.76}} \times \frac{.76}{.76 - 1} \times Sales_0^{\frac{.76-1}{.76}} - Sales^{\frac{.76-1}{.76}} - Price_0 \times (Sales_0 - Sales) \quad \textbf{(6)}$$

Thus, social costs are decreased due to the reduction in compliance costs as a result of reduced California sales, with an offsetting increase in social costs due to the loss in consumer surplus due to the price increase and sales decrease.

d. Impacts of Market Impacts on Lifetime Emission Reductions

To estimate the impact of market impacts on lifetime emissions reductions, we assume reductions in new equipment in California are compensated one-for-one by either retention of current equipment or purchase outside California, both of which leave the total California equipment stock unchanged. We assume that emission rates would be equal to baseline emissions for both the existing engines and non-California engines, and thus the mix between these two market impacts does not affect the lifetime emissions estimates. Note that this assumption is conservative (i.e., understates the offsetting increase in emissions) to the extent that the reduced scrappage applies to equipment with emissions greater than the current baseline standards (which would be the case with older equipment whose lifetime emissions rates reflect deterioration of emission controls).

F. Calculation of Effectiveness and Incremental Cost-Effectiveness

The preceding steps provide estimates of the aggregate compliance costs and lifetime emissions reductions associated with manufacturers' compliance with each alternative set of SORE emissions standards. This information is supplemented by estimates related to market impacts that affect both the effectiveness (as measured by emissions reductions) and the social costs of the three sets of alternatives.

For the results that include market impacts, the compliance costs are modified to remove compliance costs for equipment sales lost due to the price increases and to add consumer surplus losses. Similarly, the estimates of reductions in lifetime emissions for the results that include market impacts are modified to include the decreases due to fewer equipment sales in California as well as the offsetting increases in emissions from the scrappage and leakage effects.

The estimates of social costs and lifetime emissions reductions for each set of standards provides the information needed to calculate effectiveness and incremental cost-effectiveness for each of the three sets of emissions standards. Estimates of the incremental cost-effectiveness for each of the set of standards are calculated as the additional costs divided by the additional emissions reductions from one set of standards to the next more stringent standard.

III. Cost-Effectiveness Results for Alternative Sets of SORE Emission Standards Excluding Market Impacts

This section provides results for the three alternative proposals excluding the market impacts of changes in the prices of new SORE equipment in California.

A. Total Net Social Costs Excluding Market Impacts

Total compliance costs for the illustrative model year include technology costs (i.e., the additional capital costs for technologies added to engines), certification costs (i.e., additional costs for testing and certification), and net consumer fuel savings (i.e., net savings due to reductions in gasoline costs relative to electricity costs). Table 11 shows these social cost components for three sets of proposed SORE standards.

Table 11: Total Net Social Costs of Three Proposals, Without Market Impacts (2021$)

Proposal	Compliance Costs (1)	Net Fuel Savings (2)	Total Cost Increase (3)
Baseline	-	-	-
EMA	$ 39,771,000	$ 9,499,000	$ 30,272,000
EMA & Staff Interim Evap	$ 50,040,000	$ 10,341,000	$ 39,699,000
Staff ZEE	$ 1,206,142,000	$ 78,597,000	$ 1,127,544,000

Note: Figures rounded to nearest thousand. Total Cost Increase (3) is calculated as the difference of Compliance Costs (1) minus Net Fuel Savings (2). Cost components for residential walk-behind mowers—which would be equal across the three alternative proposals—are not included.

Source: Calculations as explained in text.

B. Lifetime Emissions Reductions Excluding Market Impacts

Table 12 shows the estimates of lifetime emissions excluding market impacts for the three sets of emission standards.

Table 12: Lifetime Emissions Reductions, without market effects (tons)

Proposal	Exhaust Reductions (1)	Evaporative Reductions (2)	Total Reductions (3)
Baseline	-	-	-
EMA	4,214	128	4,342
EMA & Staff Interim Evap	4,187	720	4,906
Staff ZEE	7,006	1,477	8,483

Note: Total Reductions (3) are calculated as the sum of Exhaust Reductions (1) and Evaporative Reductions (2). Emission reductions for residential walk-behind mowers—which would be equal across the three alternative proposals—are not included.
Source: Calculations as explained in text.

C. Incremental Cost-Effectiveness Excluding Market Impacts

Table 13 shows the incremental cost effectiveness as dollar per ton of CO_2 emissions reduction for each of the proposed sets of standards. The following are the key results.

- The ZEE for residential walk-behind lawnmowers would reduce lifetime emissions by 26 percent. The 60 percent reduction in emissions for other engines would reduce lifetime emissions by an additional 37 percent at a cost of about $7,000 per ton.
- The EMA & Staff Interim Evap Proposal would reduce lifetime emissions by an additional five percent at an incremental cost of about $16,700 per additional ton reduced.
- The Staff ZEE Proposal would reduce lifetime emissions by an additional 32 percent at a cost of about $304,000 per additional ton reduced.

As noted, these results do not take into account market effects (i.e., the effects of higher equipment prices on new sales and scrappage/leakage rates).

Table 13: Incremental Cost Effectiveness Excluding Market Impacts

Standard	Incremental Cost ($) (1)	Incremental Emission Reductions (tons) (2)	Incremental Cost-Effectiveness ($/ton) (3)
Baseline	-	-	-
EMA	$ 30,272,000	4,342	$ 6,972
EMA & Staff Interim Evap	$ 9,426,000	564	$ 16,700
Staff ZEE	$ 1,087,845,000	3,577	$ 304,146

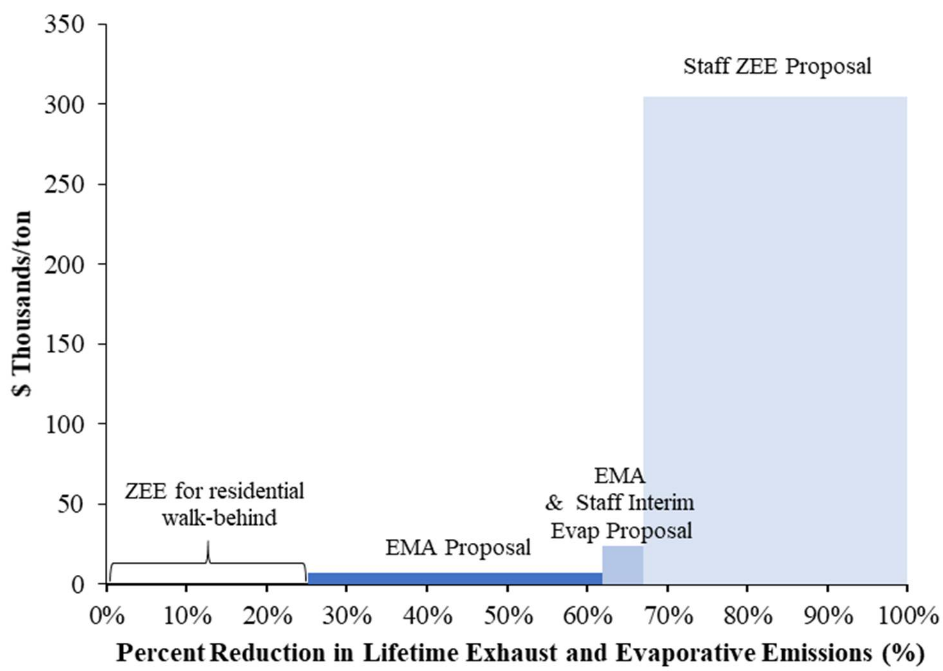
Note: Incremental Cost (1) values are rounded to the nearest thousand. Incremental cost-effectiveness (3) is calculated as the Incremental Cost (1) divided by the Incremental Emission Reductions (2). Costs and emission reductions for residential walk-behind mowers are not included in the incremental cost-effectiveness calculations for the EMA Proposal.

Source: Calculations as explained in text.

D. Effectiveness and Incremental Cost-Effectiveness of Three Proposals Excluding Market Impacts

Figure 1 shows these results of the effectiveness and the incremental cost-effectiveness of the three proposals graphically.

Figure 1: Effectiveness and Cost-Effectiveness of Three Sets of SORE Standards, Excluding Market Impacts



Source: Calculations as explained in text.

E. Potential Social Costs Not Included in the Analyses

In addition to not including the effects of market impacts, these cost-effectiveness estimates do not include the following potential categories of costs that would apply to electrification.

- *Performance losses from electric equipment*. Electrification could lead to performance losses, which would increase the full social costs to consumers and thus increase the cost per ton for emissions reductions.
- *Testing/certification costs for electric equipment.* The cost analysis assumes there are no additional testing and certification costs for electric equipment. To the extent there are such costs, the social costs would increase and thus increase the cost per ton estimates for electrification.
- *Battery disposal costs.* The cost analysis assumes no incremental disposal costs for ZEE equipment. Battery disposal may make electric equipment disposal more costly than for gasoline engines, which would increase the costs of ZEE equipment and thus increase the social cost per ton of emissions reductions.

The exclusion of these factors provides a reason that the results may understate the incremental cost per ton of the Staff ZEE Proposal.

IV. Cost-Effectiveness Results for Alternative Sets of SORE Emission Standards Including Market Impacts

This section provides information on the effects on the effectiveness and the incremental cost-effectiveness of the three proposals when market impacts are included in the analyses.

A. California New Equipment Sales Impacts of Alternative SORE Standards

As discussed above, price impacts include the per unit costs of the technologies that would be used to meet the various proposals, with costs for electrification estimated net of average annual fuel savings. Table 14 shows the calculation of the "effective price" of electrified equipment, including the per unit technology costs for conversion to electric and material costs (notably battery costs) as well as the estimated fuel savings (i.e., lifetime savings in gasoline costs relative to electricity costs based upon typical usage). Note that fuel savings are also calculated for any engine modifications that increase fuel efficiency on non-ZEE engines (e.g., switching an engine to an EFI system).

Table 14: Calculation of "Effective Price" for Electrified Equipment including Fuel Savings from Electrification

Class	Equipment	Price ($)	Electrification Costs ($)	Lifetime Fuel Usage (gallons)	Lifetime Fuel Cost ($)	Lifetime Energy Usage (kWhr)	Lifetime Electricity Cost ($)	Savings ($)	Effective Price ($)
I	Pressure Washer	$ 330	$ 2,521	157	$ 423	1,706	$ 290	$ 133	$ 2,718
I	Construction/Utility Class I	$ 650	$ 2,009	121	$ 327	1,239	$ 211	$ 117	$ 2,543
II	L/G Tractor	$ 1,500	$ 6,674	559	$ 1,510	6,421	$ 1,092	$ 419	$ 7,756
II	ZTR Commercial	$ 6,700	$ 8,318	830	$ 2,240	8,479	$ 1,441	$ 799	$ 14,219
II	ZTR Residential	$ 3,000	$ 8,305	709	$ 1,914	7,824	$ 1,330	$ 584	$ 10,721
II	Construction/Utility Class II	$ 1,000	$ 9,315	621	$ 1,675	6,889	$ 1,171	$ 504	$ 9,811

Note: To avoid disclosing confidential information, table does not include Class I and Class II generators and commercial walk-behind lawn mowers. Though not shown, fuel savings for these categories are included in the analyses.

Source: Calculations as explained in text.

Table 15 shows the net price impacts for each equipment type for each set of emissions standards. Using this change in prices, we estimate changes in new equipment sales under the three sets of standards. For the EMA and EMA & CARB Interim Evap standards, the price increases are relatively modest—between 0% and 13% across all equipment types. In contrast, the estimated price impacts are substantial for the Staff ZEE Proposal.

Table 15: Estimated Price Impacts by Equipment Type by Proposal

Class	Equipment	Price ($)	EMA	EMA & Staff Interim Evap	Staff ZEE
I	Pressure Washer	$330	12%	12%	728%
I	Construction/Utility Class I	$650	7%	6%	294%
II	L/G Tractor	$1,500	9%	12%	417%
II	ZTR Commercial	$6,700	3%	4%	112%
II	ZTR Residential	$3,000	11%	13%	257%
II	Construction/Utility Class II	$1,000	0%	7%	881%

Note: To avoid disclosing confidential information, this table does not include information for Class I and Class II generators and commercial walk-behind lawn mowers. Though not shown, price impacts for these categories are included in the analyses.

Source: Calculations as explained in text.

The estimated sales impacts of these estimated price changes are shown in Table 16. The large price increases for the Staff ZEE standards lead to estimates of substantial impacts on sales of new equipment in California.

Table 16: Estimates of Percent Reductions in California Sales by Equipment by Proposal

Class	Equipment	Price ($)	EMA	EMA & Staff Interim Evap	Staff ZEE
I	Pressure Washer	$330	-8%	-8%	-80%
I	Construction/Utility Class I	$650	-5%	-4%	-65%
II	L/G Tractor	$1,500	-6%	-8%	-71%
II	ZTR Commercial	$6,700	-2%	-3%	-44%
II	ZTR Residential	$3,000	-8%	-9%	-62%
II	Construction/Utility Class II	$1,000	0%	-5%	-82%

Note: To avoid disclosing confidential information, this table does not include Class I and II generators and commercial walk-behind lawn mowers. Though not shown, sales impacts for these categories are included in the analyses.

Source: Calculations as explained in text.

B. Effects of Market Impacts on Social Costs

The market effects will modify the social costs for the proposals in two major respects. First, the reduced California sales will reduce compliance costs, as fewer California product would install emission control technologies. Second, the reduction in California sales will reduce consumer surplus, i.e., consumer welfare from valuing products greater than the market price, as reflected in the consumer demand curve. Put another way, the loss in consumer surplus reflects the loss from being "priced out" of new equipment (sometimes referred to as "dead weight loss" and well established as a social cost in economics literature).

Table 17 shows the social costs by type of cost for the three sets of SORE emissions standards for these two major categories of social costs.

Table 17: Social Costs of Proposals Including Market Impacts (2021$)

Standard	Technology Costs	Lost Consumer Surplus	Total Cost Increase
Baseline	-	-	-
EMA	$ 29,212,913	$ 1,491,892	$ 30,704,806
EMA & CARB Interim Evap	36,975,036	1,825,873	38,800,909
CARB Final	334,101,568	207,741,534	541,843,103

Source: Calculations as explained in text.

C. Effects of Market Impacts on Lifetime Emission Reductions

In the context of market impacts, there are three components of net emissions reductions relative to the baseline conditions: (a) the demand effect (reductions in emissions due to fewer California sales); (b) the compliance effect (reductions in emissions due to lower emission standard); and (c) the leakage/scrappage effect (increases in emissions due to increased leakage and reduced scrappage). These three categories mean that the incremental impacts of a more stringent emission standard can be negative, which would occur if the leakage/scrappage effects were greater than the demand effect and the compliance effect.

Table 18 shows estimates of the lifetime emissions reductions in tons for each of the three sets of emissions reductions standards, including the market impacts.

Table 18: Lifetime Emissions Reductions by Proposal Including Market Impacts (tons)

Proposal	Exhaust Reductions (1)	Evaporative Reductions (2)	Total Reductions (3)
Baseline	-	-	-
EMA	3,970	112	4,083
EMA & Staff Interim Evap	3,875	659	4,533
Staff ZEE	2,248	490	2,738

Source: Calculations as explained in text.

D. Effectiveness and Incremental Cost-Effectiveness of Three Proposals Including Market Impacts

Table 19 shows the incremental cost effectiveness in dollars per ton for each of the three proposed sets of standards, relative to the baseline (i.e., current emission standards).

Effectiveness estimates are provided for all three proposals and are summarized as follows.

- The EMA Proposal reduces emissions by 60 percent when market effects are included, down slightly from the 62 percent reduction ignoring market effects.
- The EMA & Staff Interim Evap Proposal reduces emissions 64 percent when market effects are included, three percentage points down from the 67 percent reduction ignoring market effects
- The Staff ZEE Proposal reduces emissions by 49 percent when market effects are included, i.e., a *smaller* net reduction than the other two proposals (11 percentage points less than the EMA Proposal and 15 percentage points less than the EMA Proposal & Staff Interim Evap Proposal) and of course dramatically lower than the 100 percent reduction for the Staff ZEE Proposal when market impacts are ignored.

Table 19: Incremental Cost Effectiveness Accounting for Market Impacts

Proposal	Incremental Cost ($) (1)	Incremental Emission Reductions (tons) (2)	Incremental Cost-Effectiveness ($/ton) (3)
Baseline	-	-	-
EMA	30,704,806	4,083	7,521
EMA & Staff Interim Evap	8,096,103	451	17,969
Staff ZEE	503,042,194	*NA*	*NA*

Source: Table 17, Table 18, Calculations as explained in text.

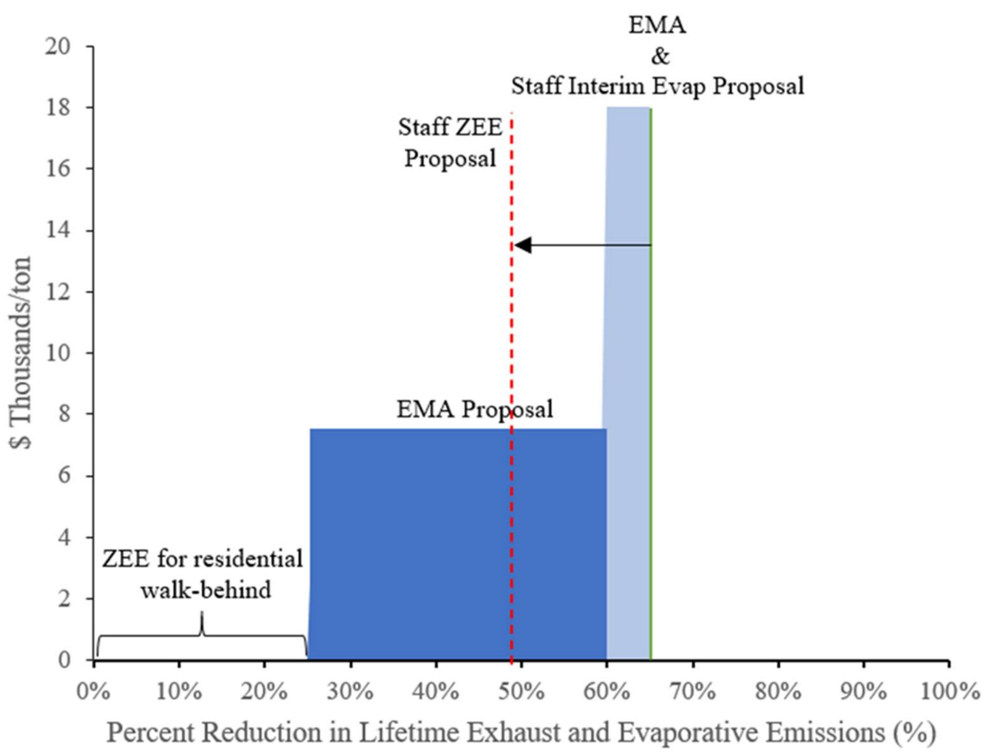
These reduced effectiveness estimates in Figure 2 result in changes in the cost-effectiveness estimates, but only two results can be shown on the graph because, as noted, the Staff ZEE Proposal leads to negative incremental effectiveness, i.e., emissions reductions are smaller than those obtained with the other two alternatives.

- The EMA Proposal achieves its 60 percent reduction at an average cost of about $7,500 per ton, up somewhat from the about $7,000 per ton when market effects are excluded.
- The EMA & CARB Interim Evap Proposal achieves its additional four percent reduction at a cost of about $17,700 per additional ton, up somewhat from the about $16,700 per ton when market effects are excluded.

- Because the Staff ZEE Proposal leads to lower emissions reductions than the other alternatives, its incremental cost-effectiveness is negative and cannot be meaningfully shown on the figure.

These results indicate that the Staff ZEE Proposal is clearly inferior to the other two proposals when market impacts are included—both the other proposals lead to greater emissions reductions at substantially lower costs.

Figure 2: Effectiveness and Cost-Effectiveness of Three Sets of SORE Standards, Accounting for Market Impacts



Source: Calculations as explained in text.

E. Social Costs Excluded from the Analyses

The three categories of potential social costs described in the previous section with respect to the analyses excluding market impacts would also be relevant for the analyses including market impacts.

- *Performance losses from electric equipment*. Electrification could lead to performance losses, which would increase the full social costs to consumers and thus increase the cost per ton for emissions reductions. Perceived performance losses also may further delay scrappage of old equipment and increase leakage from other states.

- *Testing/certification costs for electric equipment.* The cost analysis assumes there are no additional testing and certification costs for electric equipment. To the extent there are such costs, the social costs would increase and thus increase the cost per ton estimates for electrification.
- *Battery disposal costs.* The cost analysis assumes no incremental disposal costs for ZEE equipment. Battery disposal may make electric equipment disposal more costly than for gasoline engines, which would increase the costs of ZEE equipment and thus increase the social cost per ton of emissions reductions.

The exclusion of these factors provides a reason that the results may understate the incremental cost per ton of the Staff ZEE Proposal.

V. Limitations of the Alternatives Considered in the Staff Economic Analyses

The Staff economic analyses contained in the ISOR and SRIA do not consider alternatives that differ in their final stringency, as all alternatives presume that ZEE standards will be required both for exhaust and evaporative emissions for all SORE equipment. (The alternatives differ in timing of the final ZEE standards from MY 2024 to MY 2028, as discussed below.)

A. Alternatives Provided in the Staff Economic Analyses

Table 20 summarizes the policy alternatives as considered in the Staff Economic Analysis.

Table 20: CARB Staff Alternatives

	Starting Year for ZEE Requirement	
Scenario	**Non-Generators**	**Generators**
Proposed Amendments	2024	2028
Alternative 1	2024	2024
Alternative 2	2026	2030
Small Business Alternative	2028	2032

Note: Alternative 2 has increased stringency for exhaust emissions in MY 2024 and MY 2025.

Source: CARB 2021c

B. Guidelines for Alternatives in Economic Evaluations

Both the EPA Guidelines and textbooks provide guidance on the development of alternatives when evaluating a proposed regulation or project.

1. U.S. Environmental Protection Agency

EPA's *Guidelines for Preparing Economic Analyses* (EPA 2014) note the importance of comparing the preferred regulatory option to alternatives, particularly alternatives that differ in stringency:

> When presenting the results of a BCA, the expected benefits and costs of the preferred regulatory option should be reported, together with the expected benefits and costs of alternative approaches. OMB's *Circular A-4* requires that at least one alternative be more stringent and one less stringent than the preferred option, and the incremental costs and benefits would be reported for each increasingly stringent option. (EPA 2014, p. 11-2)

As noted above, the alternative SORE standards identified and evaluated in the Staff Economic Analyses all presume ZEE requirements for all SORE equipment, differing only in the timing of the final ZEE standards.

2. Textbooks on Benefit-Cost and Cost-Effectiveness Analyses

The importance of evaluating alternatives with a range of stringency is noted by economists and policy analysts as important to provide decision makers with full information on the choices before them. Examples provided in textbooks provide illustrations of the usefulness of evaluating alternatives that differ substantially in their costs and effectiveness. For example, in their textbook, Boardman et al. (2018) provide an example of a cost-effectiveness comparison in which the costs of the three illustrative mutually exclusive alternatives to improve 12th grade test scores are $50 million, $150 million, and $300 million. This wide range provides the school board with information on the additional gains that might be achieved in student test scores if more resources are devoted to the program. This illustrative case is similar to the situation with respect to alternative SORE emission standards—it would be useful for CARB to have information on the additional gains in air quality (in this case as measured by lifetime reductions in emissions) that would result from increasingly stringent standards.

To evaluate the cost-effectiveness of the alternatives, these textbooks note the importance of evaluating the incremental costs and incremental effectiveness of increasing costly alternatives. Boardman et al. (2018), for example, note that "to make policy recommendations it is useful to compute incremental CE ratios" which measure "the incremental cost per unit improvement in effectiveness relative to the next less costly alternative." Boardman et al. (2018) provides a graphical example of plotting the incremental cost-effectiveness of the increasingly expensive programs.

The incremental cost-effectiveness analysis recommended by textbooks is equivalent to the graphs provided in the cost-effectiveness analysis in this report, which cover a wide range of potential social costs. In contrast, the economic analyses provided by the Staff do not allow CARB to evaluate the incremental gains (either as effectiveness or quantified benefits) that are achieved as emission standards are made more stringent, as all of its alternatives assume the same final stringency (i.e., ZEE for all SORE engines and equipment).

C. Implications for Sufficiency of SORE Alternatives Evaluated by Staff

In summary, the lack of alternatives that differ in final stringency in the Staff economic analyses (as reflected in the ISOR and SRIA) deprives the CARB of important information as they decide on the final set of SORE emission standards.

VI. Conclusions

The following are the two principal conclusions of our study of the effectiveness and cost-effectiveness of three alternative sets of SORE emission standards (EMA Proposal, EMA Proposal & Staff Interim Evap Proposal and Staff ZEE Proposal).

- Even ignoring market price effects, the Staff ZEE Proposal is dramatically less cost-effective than the two less stringent alternatives, with the additional tons that are reduced due to the Staff ZEE Proposal costing more than $300,000 per additional ton.
- When market price effects are included, the Staff ZEE Proposal is clearly inferior to the other two proposals, as both of the other proposals would yield greater emission reductions at dramatically lower costs.

The Staff economic analyses in the SRIA and ISOR are severely limited by their failure to evaluate a range of standards that differ in final stringency, as the Staff ZEE Proposal and all alternatives assume eventual ZEE standards for all SORE equipment. The lack of a wide range of alternative stringencies—that allow for estimates of the incremental costs and benefits of increasingly stringent final standards—means that the Staff have not provided the Board or the public with important economic information on potential alternative SORE standards.

References

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Appendix A: Survey Instrument

This appendix provides information on the survey used to collect data from the four manufacturers on their engines and the cost and effectiveness of potential emissions reduction technologies. We include the instructions and the survey instrument. The examples provided are for Class I engines, but the survey is the same for Class II engines.

A. Baseline Engine Information

This section summarizes the survey instructions and survey instrument to obtain baseline engine family information.

1. Survey Instructions

For baseline engine information, the survey instructions were as follows.

> This spreadsheet survey is divided into separate sheets for Class I engines and Class II engines. The instructions are the same for each class.
>
> *"Class I Engines"*
>
> The "Class I Engines" tab lists your Class I engines. Group your engines into no more than 6 appropriate groups.
>
> For example, these groups may be based on engine size, displacement, power, useful life, application--respondents can choose whatever criteria make the most sense in terms of similarities in emissions level and applicability of emissions reduction technology.

Respondents were asked to provide the following information for each engine family:

- Engine Group
- 2018 Production Volume
- Projected 2024 CA Sales
- Applications
- Useful Life
- Displacement
- Max Engine Power
- Max Engine Test Speed
- Crankshaft Orientation
- Country
- HC-NOx Cert Level

2. Survey Instrument

Figure A-1: Survey Instrument for Engine Information

Class I Engines

Group your engines into no more than 6 categories - your choice of categories (ie: size, application, power, useful life, etc)

Group	Group Description
1	
2	
3	
4	
5	
6	

Illustrative engine family examples used in draft version of template--company engine information as pulled from EPA database will be provided

Engine Group	Engine Family	Production Volume (2018)	Projected Volume CA (2024)	Applications	Useful Life	Displacement (CC)	Max Engine Power	Max Engine Test Speed	Crankshaft Orientation	Country 1	HC-NOx Cert Level

B. Technology Costs

1. Survey Instructions

The following are the survey instructions for manufacturers to provide information on the costs of alternative emission control technologies.

Costs

The three technology options are Engine Modifications, Aftertreatment, and Electrification. There is one cost chart for each of these technologies and for each group of engines.

For Engine Modifications, include any and all modifications you could use to reduce emissions. The list provided is not exhaustive.

If you would prefer not to list the costs out separately, you may simply provide a total cost.

Assume costs for achieving minimum feasible emissions levels (e.g., what feasible catalyst would provide maximum feasible emission reductions, not just what is the cheapest)

The table is broken into capital costs and per engine costs.

At this stage, we are assuming separability in costs of the different technologies; interaction effects on costs (e.g., of simultaneously applying Technology 1 and Technology 2) will be discussed with companies after the first round of data collection.

Any adverse performance impacts or cost information that cannot be quantified here can be included in the comments section on the "Qualitative" sheet.

Respondents were asked to provide estimates of the following costs for each component of the emissions control, as available and relevant:

- **New Tooling** — Cost of tooling that will have to be changed. If common tooling is shared between engine groups, report the total tooling cost divided by fraction of all engines this group represents. Also identify in a comment all groups sharing this tooling.
- **Old Tooling** — If compliance requires tooling changes before existing tooling is fully amortized, please indicate unamortized amount.
- **Equip and Integration** — Insert costs of any new equipment or other costs required for integrating the item into the engine other than tooling. If cost is shared between engine models, report the total tooling cost divided by fraction of all engines this model represents.

- **Facilities** — Does item require any building modifications, new buildings, etc.
- **R&D and Engineering** — R&D and Engineering Costs Associated with development and design of the Item
- **Certification and Testing** — Estimated increase in certification and/or testing costs resulting from this item
- **Roll Out** — Costs associated with training of production line workers, modification of owners and repair manuals, training for service personal, consumer education materials, etc.
- **Amortization Period** — Number of years over which the capital costs will be recovered
- **Materials** — Materials and/or parts costs per unit
- **Machining** — Any additional machining costs not included in either the production capital or materials cost
- **Assembly** — Increased cost of assembly
- **Testing** — Per unit cost of any additional inspection or testing required for this item
- **Warranty** — Indicate increase in warranty costs on a per unit basis

2. Survey Instrument

Figure A-2: Survey on Technology Costs

2019 EMA CARB - Cost Effectiveness Study

Engine Cost Increases and Emission Reductions

Class I Engines

Directions: There is one chart for each engine group and each Technology option. Fill out costs for each component or alternatively, provide total cost of the technology option. Assume costs for achieving maximum feasible emission reductions.

Technology Costs

Engine Group 1:

Technology 1:
Engine Modifications

Per general instructions, we are interested in the maximum feasible emissions reduction for each technology option. Companies can choose the specific combination of engine modifications that meets this criterion (placeholder examples below, but others should be included if relevant)

		Production Capital Costs [Total $]									Variable Costs [$/engine]					
	Item	New Tooling	Old Tooling	Equip and Integration	Facilities	R&D and Engineering	Certification and Testing	Roll Out	Amortization Period	TOTAL	Materials	Machining	Assembly	Testing	Warranty	Total Variable $/Eng
1	Fuel Injection									$0						$0
2	EGR									$0						$0
3	Air Injection									$0						$0
4	Calibration									$0						$0
5	Other									$0						$0
6										$0						$0
7										$0						$0
8										$0						$0
	TOTAL	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0

Technology 2:
Aftertreatment (Catalysts)

Per general instructions, we are interested in the maximum feasible emissions reduction for each technology option. Please provide information for the catalyst option that achieves the greatest reductions.

		Production Capital Costs [Total $]									Variable Costs [$/engine]					
	Item	New Tooling	Old Tooling	Equip and Integration	Facilities	R&D and Engineering	Certification and Testing	Roll Out	Amortization Period	TOTAL	Materials	Machining	Assembly	Testing	Warranty	Total Variable $/Eng
1										$0						$0
2										$0						$0
3										$0						$0
4										$0						$0
5										$0						$0
	TOTAL	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0

Technology 3:
Electrification

Include relevant components for replacing engine with battery technology (or hybrid option, if more appropriate)

		Production Capital Costs [Total $]									Variable Costs [$/engine]					
	Item	New Tooling	Old Tooling	Equip and Integration	Facilities	R&D and Engineering	Certification and Testing	Roll Out	Amortization Period	TOTAL	Materials	Machining	Assembly	Testing	Warranty	Total Variable $/Eng
1	Battery									$0						$0
2	ECU									$0						$0
3										$0						$0
4										$0						$0
5										$0						$0
6										$0						$0
7										$0						$0
8										$0						$0
	TOTAL	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0

C. Emission Reductions

1. Survey Instructions

The following are the survey instructions for manufacturers to provide information on the effectiveness of emission control technologies, i.e., the emissions reductions.

Emissions

Specify the emissions you could achieve with the components specified in the Cost table.

Both "zero hour" and "end of useful life" emissions rates were requested for all engine groups. Emission reductions of alternative controls were allowed to be additive/interactive, if relevant.

2. Survey Instrument

Figure A-3: Survey Instrument for Emissions Reductions Information

Baseline Emissions		HC [g/kw-hr]	NOx [g/kw-hr]	HC+NOx [g/kw-hr]
Current Engine	0 hr (Engine out)			
	Durability Period (Engine out)			

Emissions w/ Technologies

Emissions Technology Interactions 0 hr		0 hr					
		HC [g/kw-hr]:		NOx [g/kw-hr]:		HC+NOx [g/kw-hr]:	
Technology		Technology on its own	Paired w/ Tech 2	Technology on its own	Paired w/ Tech 2	Technology on its own	Paired w/ Tech 2
1	Engine Modification						
2	Aftertreatment Devices						
3	Electrification						

Emissions Technology Interactions Durability Period hrs		Durability Period hrs					
		HC [g/kw-hr]:		NOx [g/kw-hr]:		HC+NOx [g/kw-hr]:	
Technology		Technology on its own	Paired w/ Tech 2	Technology on its own	Paired w/ Tech 2	Technology on its own	Paired w/ Tech 2
1	Engine Modification						
2	Aftertreatment Devices						
3	Electrification						

D. Qualitative Considerations

1. Survey Instructions

The following are the survey instructions for manufacturers to provide information on the qualitative considerations of emission control technologies.

Class [x] Qualitative

This sheet captures qualitative effects that may not be obvious with cost data.

For customer effect, mark each technology for each group as "Positive," "No effect," or "Negative"

Describe the effect (e.g., usability impact, weight, durability, etc.)

Include any other comments in the "Additional Comments" column.

Respondents could provide qualitative considerations for the following:

- Customer Effect of Engine Modification
- Additional Comments related to Engine Modification
- Customer Effect of Aftertreatment
- Additional Comments related to Aftertreatment
- Customer Effect of Electrification
- Additional Comments related to Electrification

2. Survey Instrument

Figure A-4: Survey on Qualitative Considerations

2019 EMA CARB - Cost Effectiveness Study
Qualitative Assessment

Class I Engines

The purpose of this sheet is to provide an opportunity to make qualitative comments regarding implementation of these technologies

Group	Group Description	Customer Effect of Engine Modification	Additional Comments related to Engine Modification	Customer Effect of Aftertreatment	Additional Comments related to Aftertreament	Customer Effect of Electrification	Additional Comments related to Electrifiction
1							
2							
3							
4							
5							
6							

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