TCEQ Contract 582-19-92744
TCEQ Work Order 582-23-42148-004
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QUANTIFYING POTENTIAL EMISSIONS REDUCTIONS ASSOCIATED WITH FEDERAL PHASE 3 NONROAD SMALL SPARK-IGNITION (SI) ENGINE REGULATORY COMPLIANCE AND LAWN AND GARDEN (L&G) EQUIPMENT ELECTRIFICATION

FINAL REPORT

Prepared for:

Texas Commission on Environmental Quality
Air Quality Division

Prepared by:

Eastern Research Group, Inc.

June 30, 2023

ERG No. 0422.00.004

Quantifying Potential Emissions Reductions Associated with Federal Phase 3 Nonroad Small Spark-Ignition (SI) Engine Regulatory Compliance and Lawn and Garden (L&G) Equipment Electrification

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ACRONYMS

ABS	Address-Based Sampling
ABT	Averaging, Banking and Trading
BSFC	Brake-Specific Fuel Consumption
CARB	California Air Resources Board
CO	Carbon Monoxide
CS	Chainsaw
CDS	Computerized Delivery Sequence
DF	Deterioration Factor
DFW	Dallas-Fort Worth
EO	Executive Order
EMA	Engine Manufacturers Association
ERG	Eastern Research Group
FEL	Family Emission Limit
HC	Hydrocarbon
HH	Handheld
HHB	Handheld Blower
HP	Horsepower
kW	Kilowatt
L&G	Lawn and Garden
L-head	Side-valve engine configuration
MOVES	Motor Vehicle Emissions Simulator
NAR	Non-Attainment Region
NHH	Non-handheld
NO_x	Nitrogen Oxides
OPEI	Outdoor Power Equipment Institute
OSD	Ozone Season Day
PLT	Production Line Testing
PM	Particulate Matter
QA	Quality Assurance
QC	Quality Control
SCC	Source Classification Code
SI	Spark Ignition
TB	Trimmer/Brushcutter
TCEQ	Texas Commission on Environmental Quality
TPD	Tons Per Day
TexN2	Texas Non-road version 2 utility, compatible with MOVES model
USPS	United States Postal Service
VOC	Volatile Organic Compounds
WBM	Walk Behind Mower
ZEE	Zero Emission Equipment
ZHL	Zero Hour Level

EXECUTIVE SUMMARY

The Texas Commission on Environmental Quality (TCEQ) contracted with Eastern Research Group, Inc. (ERG) to quantify the emissions impacts from the operation of nonroad small spark ignition (SI) engines complying with 50-state emission standard certifications as well as the operation of electric lawn and garden (L&G) equipment, neither of which are currently accounted for in the United States Environmental Protection Agency's (EPA) Motor Vehicle Emissions Simulator (MOVES) model or the TCEQ Texas Nonroad version 2 (TexN2) utility. Under this work assignment ERG used a range of methods including survey work and published data to assess and quantify these impacts which the TCEQ may include in on-going state implementation planning.

Certification Compliance Assessment

The goal of the certification compliance assessment was twofold: to determine if 50-state engine certifications (engine families certified to meet both federal and California requirements) result in emissions benefits beyond those needed for federal compliance alone; and to determine whether compliance estimated using the EPA emissions model (MOVES3, the basis for the TexN2 utility) is sufficiently accurate. An initial scoping study determined that industry is largely certifying 50-state engine families, and the MOVES3 emission rate assumptions for post-2012 small SI nonroad engines remain unchanged from the original 2008 rulemaking forecast. In addition, after initial discussion with trade association representatives, suitable data appeared to be available from industry that would allow for quantification of exhaust emission compliance including 50-state engine certification families. This data would include business confidential production volume data and would be provided to ERG after entering into a contractor-manufacturer confidentiality agreement.

Current manufacturers of small SI non-handheld engines were contacted, and two levels of data were requested. The primary data request was for copies of final federal compliance submittals for small SI non-handheld nonroad engines. The secondary request asked for additional information on each engine family including a listing of applications, valve technology and ownership types.

A limited number of compliance submittals were received and reviewed, although the final response was too small to complete an emissions impact evaluation for regulatory compliance. However, industry response was sufficient to update the market share between side-valve and overhead valve engines, which in turn impacts emission rates for many small SI engines. Updating the valve location mix in the TexN2 utility results in a 1 percent reduction in small SI engine volatile organic compound (VOC) emissions, and a 4 percent increase in nitrogen oxides (NO_x) emissions for the 2023 calendar year, as discussed in the Inventory Results section.

Residential Lawn and Garden Equipment Update

ERG designed and executed a random sample survey of residents of single-family detached homes across Texas to determine the number of residential lawn and garden (L&G) equipment units owned and operated during the 2022 calendar year, including breakouts by technology type (i.e., 2-stroke gasoline, 4-stroke gasoline, and electric). The survey stratified counties into urban and rural groupings based on the assumption that L&G equipment ownership rates, equipment type distributions, and technology mixes (i.e., gasoline vs electric) would be substantially different in urban and rural areas. The data collection plan targeted 400 completed surveys within each stratum, with a confidence level of 95% for a 5% margin of error. 780 completed surveys were received, 402 for the rural stratum, and 378 for the urban stratum, with broad representation across the state.

ERG validated the responses to assess consistency with available information on L&G equipment characteristics and use. ERG then applied the survey findings on equipment ownership rates to estimate statewide county-level populations, which in turn were used to update annual and ozone season day VOC and NO_x emission estimates for each Texas county for the 2022 base year. The survey-based non-electric equipment population estimates were substantially higher (71 percent on the whole) than the default population estimates assumed by the current TexN2 utility, as discussed in the Statewide Equipment Population Estimation section.

The non-electric equipment counts were updated in the TexN2 population lookup tables for the 2022 base year to estimate revised annual and ozone season day emissions for VOC and NO_x by equipment type. The net change in emissions at the equipment type level corresponds to the relative change in total equipment populations. Overall, the non-electric population updates resulted in a statewide VOC increase of 16 tons per ozone season day (64 percent), and a NO_x increase of 1 ton per ozone season day (32 percent) for the 2022 calendar year. While there was an increase in overall emissions due to the substantially higher non-electric equipment counts from the survey, there was a decrease in emissions due to accounting for electric equipment. Had electric equipment been assumed to be gasoline powered instead (as is done in EPA's MOVES model), statewide VOC emissions would have increased by an additional 1.3 tons per ozone season day and NO_x emissions would have increased by an additional 28.5 tons per ozone season day.

ERG also forecast the 2022 base year non-electric equipment populations used in TexN2 to future years applying the same growth factors included in MOVES3. ERG assumed the 2022 electrification levels from the survey would remain constant into the future, a conservative assumption as electric sales are likely to increase across most/all equipment types (see Emissions Forecasting and Back-Casting for details). ERG also accounted for past changes in electrification fractions based on industry sales trend data to adjust the TexN2 equipment populations prior to the 2022 calendar year.

ERG provided the TCEQ with a revised version of the TexN2 utility incorporating the small SI valve location distribution as well as the updated residential L&G equipment populations.

I. INTRODUCTION

Purpose

The purpose of this project is to quantify the emissions impacts from the operation of nonroad small SI engines with 50-state certifications as well as the operation of electric L&G equipment, neither of which are currently accounted for in the EPA's MOVES model or the TCEQ's TexN2 utility. Under this work assignment ERG used a range of methods including published data and survey work to assess and quantify these emissions impacts which represent previously unaccounted for categories that the TCEQ may include in on-going state implementation planning.

Report Organization

This report presents a comprehensive overview of the activities undertaken during the project. The report first presents the methodology and findings of the federal Phase III nonroad small SI engine regulatory compliance study, followed by a corresponding description of the L&G equipment electrification analysis. Each section highlights major activities and key findings, provides pertinent analysis, describes any problems encountered and associated corrective actions, and (where applicable) details relevant statistics including data, parameter, or model completeness, accuracy, and precision as appropriate. The report concludes with a summary of key findings and recommendations for future analysis. The appendices provide detailed data references, documentation of the calculations used to compute emissions impacts and the results of the quality assurance measures performed.

II. FEDERAL PHASE 3 NONROAD SMALL SI ENGINE REGULATORY COMPLIANCE STUDY

This section is organized into three subsections. The first subsection documents the initial scoping effort conducted to determine the potential extent of the emissions impacts associated with small SI engine 50-state compliance. The next subsection presents the data collection and analysis approach followed to execute the study. The section concludes with details regarding emission calculation methods and estimated emission impacts for VOCs and NO_x for affected equipment operating in Texas.

Initial Scoping Effort

The following presents the results of the initial scoping study conducted by ERG examining small SI nonroad engine regulatory compliance in Texas. The overall goal of the regulatory compliance review is twofold: to determine if 50-state engine certifications (engine families certified to meet both federal and California requirements) result in emissions benefits beyond those needed for federal compliance; and to determine whether compliance as estimated using the EPA emissions model (i.e., MOVES3, the basis for the TexN2 model) is sufficiently accurate.

The first task of the initial scoping study was to determine whether suitable data exists and can be provided in a timely manner to meet the goals of the regulatory review and emissions inventory assessment. The scoping included a series of contacts with industry and industry trade associations, a review of federal and California certification requirements, and a review of MOVES3 modeling methods.

The key findings of the scoping study are as follows.

- It was confirmed that industry is largely certifying 50-state engine families as per a review of public certification databases and discussions with industry.
- The MOVES3 emission rate assumptions for Phase 3 small SI nonroad standards remain unchanged from the original 2008 rulemaking forecast.
- Suitable data appeared to be available from industry that would allow for the quantification of exhaust emissions compliance of the federal certification region, implicitly including 50-state certification families. This data would include business confidential production volume data and would be provided to ERG after entering into a contractor-manufacturer confidentiality agreement.
- The most significant difference between the California and federal certification requirements is California's diurnal evaporative requirement for engines over 80 cc displacement. It was determined that because evaporative emissions control equipment is individually certified, the canisters needed to meet the diurnal requirement are not installed on equipment sold in the federal certification region. For this reason, it was concluded there are likely no additional evaporative credits to be taken for 50-state certifications beyond the standard assumptions of the MOVES3 (and TexN2) model.

The following presents the scoping study elements and recommended next steps.

Initial Contacts and Feedback

Multiple rounds of contacts were made with the Truck and Engine Manufacturers Association (EMA) and one small SI nonroad engine manufacturer. Industry validated key elements of the scoping study relating to certification compliance approaches, underlying emissions control technologies, and industry changes since the original EPA Phase 3 rulemaking. A draft data request (described below) was reviewed and found to be generally acceptable to industry representatives provided that contractor-manufacturer confidentiality agreements were completed in advance.

Representatives also described changes in the small SI nonroad engine manufacturing industry since the Phase 3 rulemaking. Tecumseh Products closed its engine manufacturing division in December 2008, a fact pertinent to the production of L-head (side-valve) engines, described below. Honda may also be exiting the small SI nonroad engine sector in 2023 rather than pursue electrification of its product line, and has made an announcement in November 2022 that it would stop making and selling walk-behind mowers in the U.S.

MOVES3 Review

A review of MOVES3 modeling assumptions and emission rates for small SI nonroad engines was completed. Nonroad SI engine emission rates have not been updated since the NONROAD2008a model, and assumptions governing current certification (Phase 3 for Class I and II engines) is based on a forecast that has not been revised with actual historical data.[1] The potential issues associated with relying on the forecasted estimates from 2008 versus actual, up to date compliance for the regulatory review are as follows.

1. Actual compliance margins may be substantively different.
2. Compliance allows for a flexible useful life/durability certification (ranging from 250 to 1,000 hours); actual industry-mean durability may be substantially different.
3. For exhaust emissions from Class I engines, MOVES3 has distinct emission rates for side-valve (aka L-head) and overhead valve engines. MOVES3 assumes a 60 percent L-head market share for Phase 3-compliant engines, whereas industry has indicated that L-head engine technology is no longer manufactured in the U.S. Tecumseh Products was the leading manufacturer of L-head engines, but it is no longer in business. Other manufacturers estimated the industry stopped selling L-head engines with model year 2017.

1 As per nonroad technical reports: https://www.epa.gov/moves/nonroad-technical-reports.

Exhaust Certification Procedures

A review of California and federal engine certification requirements was completed. The California and federal exhaust certifications are generally harmonized in terms of emission standards and most certification requirements. However, one distinction was identified in the averaging, banking, and trading (ABT) programs, with California ABT credits expiring after 5 years while EPA credits have no expiration. The expiration in California may impact federal certifications as well, given the preponderance of 50-state industry certifications.

Industry contacts also discussed how production line testing (PLT) requirements for the industry interact with certification compliance. Quarterly PLT of exhaust emissions is required to confirm certification results, and running changes to model year certifications may occur because of PLT results. Moreover, industry banks ABT credits as an "insurance policy" against unexpected PLT results. This interplay between PLT and certification may lead to additional compliance margins beyond that which would otherwise occur if PLT requirements were absent. (Note that the PLT requirements are largely the same between California and federal certification regions.)

Evaporative Certification Procedures

There is a significant difference between federal and California evaporative certification requirements. For small SI engines greater than 80 cc displacement, California includes a diurnal test requirement that has no federal equivalent. This diurnal test requirement results in applications being equipped with evaporative canisters. ERG's initial assumption was that 50-state evaporative engine certifications would mean that canister-equipped small SI nonroad engines would be sold in the federal certification region representing a potential emission credit that is not addressed by the MOVES3 model. It was also noted that California Air Resources Board (CARB) Executive Orders (EOs) can be the basis for federal evaporative certification approval.[2]

However, multiple industry representatives indicated that canisters will not be present in 50-state engines sold in the federal certification region even if the California EO is used as the basis for federal certification. While EPA permits the submittal of the CARB EO to support evaporative certification in the federal region, and those EOs include the certification of canisters (on engines over 80 cc), in these cases *it is the individual evaporative components that are certified – which is not to say that all the components are actually installed*. In fact, industry is disincentivized from including canisters in equipment in the federal certification region because it would present an added cost with no regulatory requirement for this control. In short, EPA evaporative certifications of 50-state engines include the canister test, but those

2 Beyond the California diurnal test requirement, California and EPA evaporative certification requirements include other minor differences, primarily in the form and evolution of certification fuels, which follow onroad regulatory changes. Regulatory technical amendments for small nonroad SI engines have been passed by EPA to ensure as much overlap and harmonization as possible. Manufacturers have the option to complete and submit dual testing for 50-state evaporative family certifications. "Cert Based CARB Exec Order" is a data field in the EPA public certification database related to evaporative family certification. This field was populated with "Yes" in over 700 instances since model year 2011 (about a 10 percent frequency) meaning that separate federal evaporative component testing was not completed for 50-state families. Approval of the California EO then becomes a requirement for federal certification as well.

canisters are not included in the sales of the equipment outside California, and only California equipment sales will include the additional evaporative control from the canister.

Exhaust Data Request

A primary and secondary data request was submitted for industry review and found to be acceptable along with signed confidentiality agreements.

The primary data request asked manufacturers to provide their final federal ABT submittals for model years 2012 and later (the model years subject to Phase 3 standards). From the ABT submittal, the data request would apply to the worksheet "Current MY Credit Calc-EXHAUST" found in the EPA ABT template.[3] These data provide key data fields for each engine family certification including:

- Engine Displacement (cc)
- Load Factor
- Power
- Useful Life (hours)
- Production Volume
- Family Emission Limit (FEL) (g/kW[4]-hr)
- HC[5]+NO_x Standard (g/kW-hr)

This data can support the evaluation of actual exhaust compliance margins and industry average useful life. While production volume data and engine displacement listings are considered business confidential,[6] industry indicated that supplying these reports for evaluation would be achievable.

A secondary data request was also developed and reviewed by industry. For each engine family, the following information was requested.

- Listing of nonroad applications (e.g., walk behind mower, etc.).
- Primarily commercial or private ownership
- Side-valve or overhead valve technology

This information would allow for mapping engines to applications in the MOVES3 model and to quantify the side-valve market share. One manufacturer indicated a willingness to provide this information.

[3] https://www.epa.gov/ve-certification/averaging-banking-and-trading-abt-template-small-nonroad-spark-ignition-si-engine.

[4] Kilowatt (kW)

[5] Hydrocarbon (HC)

[6] Engine displacements are manufacturer-specific and could be used to identify individual manufacturers.

Recommended Next Steps

Based on the results of the MOVES3 review and industry's expressed willingness to provide certification compliance data, ERG recommended the continuation of the regulatory review via industry survey. Based on this assessment the TCEQ authorized ERG to initiate the data request, process the data, quantify the differences between actual and forecasted compliance, and develop modified MOVES3 data tables necessary for estimating emissions impacts.

Data Collection and Analysis Approach

Following approval from the TCEQ, follow up contacts were made with nonroad engine manufacturers and affiliated trade associations to provide business confidential data as described above. Manufacturer data were subsequently received and reviewed.

A more detailed review of EPA's Phase 3 regulatory compliance was also completed for comparison with manufacturer data. Table 1 presents the current emissions standards for small (≤19 kW) spark-ignition (SI) nonroad engines. The Phase 3 rulemaking applies only to non-handheld (NHH) applications and covers two classes of engines. The data collection focused on Class I and II regulatory compliance with the $HC+NO_x$ standard of 10 and 8 g/kW-hr, respectively.[7]

Table 1. Current Emission Standards for Small SI Nonroad Engines

Engine Class	Type	Engine Displacement (cc)	Power Range (HP)		Standard (g/kW-hr)	
			Min	Max	$HC+NO_x$	CO*
Class I	NHH	< 255	3	6	10	610
Class II	NHH	≥ 255	6	25	8	610
Class III	HH	< 20	0	1	50	805
Class IV	HH	≥ 20, < 50	1	3	50	805
Class V	HH	≥ 50	3	6	72	603

* There are alternate carbon monoxide (CO) standards for auxiliary marine generators as well as for certification testing completed with CARB LEV3 gasoline.

[7] Note there are no particulate matter (PM) standards for these engines.

Importantly, compliance with the HC+NO_x standard allows for ABT of excess credits within a manufacturer's product line as well as between manufacturers.[8] The calculation of ABT credits is proportional to useful life which can be set at 125, 250, or 500 hours for Class I engines, and 250, 500 or 1,000 hours for Class II engines.

MOVES3 Phase 3 Compliance Assumptions

ERG reviewed EPA's memorandum to the regulatory docket documenting how the Phase 3 modeling assumptions were developed.[9] EPA's estimated compliance with the Phase 3 standards has not changed since the original 2008 rulemaking. This finding was based on a review of emission rates and other modeling assumptions, which remain unchanged over successive versions of EPA's MOVES model (and the predecessor model known as NONROAD) since their original development as part of the rulemaking process.

The underlying MOVES3 exhaust emission rate data for Phase 3 engines are defined for the following classes and valve locations.

- Class I, side-valve
- Class I, overhead valve
- Class II, overhead valve

Emission rates are a function of accumulated hours and are defined by a zero-hour level (ZHL) and deterioration factor (DF) formula, which relies on Coefficient A, as shown in the following equations.

$$EmissionRate_{Aged} = ZHL \times DF$$

$$DF = 1 + A \times \left(\frac{CumulativeHours \times Load}{MedianLife}\right)^{0.5}$$

Median life in hours is defined at full engine load. Both the load factor and median life are application-specific (e.g., walk-behind mowers, trimmers, etc.) MOVES3 inputs, which means that determination of regulatory compliance is also application-specific.

Table 2 presents EPA's estimated values for ZHL and Coefficient A, which form the basis for the MOVES3 emission rates.

[8] Compliance is based on each manufacturer's production-weighted average of FELs. FELs for a given engine family can exceed the standard as long as the overall corporate average is below the standard.

[9] "Phase 3 Technology Mix, Emission Factors, and Deterioration Rates for Spark-Ignition Nonroad Non-handheld Engines at or below 19 Kilowatts for the NONROAD Emissions Inventory Model," from Phil Carlson to Docket EPA-HQ-OAR-2004-0008, March 8, 2007.

Table 2. Docket Memorandum Phase 3 Emission Rate Parameters

Pollutant	Parameter	Class I, Side-valve	Class I, Overhead Valve	Class II, Overhead Valve
HC	ZHL (g/kW-hr)	5.60	5.09	4.25
	A (maintained engine)	0.566	0.566	0.566
	A (in-use engine)	0.797	0.797	0.797
NO_x	ZHL (g/kW-hr)	1.40	1.91	1.35
	A (maintained engine)	0.044	0.044	0.044
	A (in-use engine)	0.302	0.302	0.302

EPA defines two versions of Coefficient A: one for a "well-maintained" engine and one for an average "in-use" engine. The in-use engine coefficient is a weighted average of 60 percent well-maintained and 40 percent malmaintained. The ZHL and Coefficient A for the in-use engine case are equal to those in the MOVES3 model data tables.[10] EPA estimated the values of Table 2 as follows.

- The split of HC+NO_x into HC and NO_x from Phase 2 engines was also assumed for Phase 3 engines.
- The ZHL was calculated as a 70 percent reduction of the Class I and Class II standards of 10 and 8 g/kW-hr, respectively, based on engineering assumptions.
- The well-maintained version of Coefficient A was calculated from the ZHL of the Class I (side-valve) case assuming an exact regulatory compliance of 10 g/kW-hr at 125 accumulated hours, with the load and median life values for a lawnmower.[11] This derivation is an engineering assumption. The 0.566 value was applied to all Class I and II engines.
- For the in-use version of Coefficient A, the malmaintained emission level was based on agency testing of Class I engines. The 40 percent malmaintenance rate was based on a survey. The malmaintenance increment was added to the estimated emissions at 125 hours for the Class I (side-valve) lawnmower, and the "in-use" Coefficient A was then calculated. This in-use Coefficient A was applied to all Class I and II engines.

Finally, the underlying split of Class I engines by valve location was set to 40 percent overhead valve and 60 percent side-valve. This split has not changed since the 2008 rulemaking. It is described in the docket memorandum as an EPA "approximation".

In summary, the quantity of data supporting the Phase 3 modeling assumptions is limited, with the only regulatory compliance calculation completed being specific to Class I, side-valve lawn mowers with an assumed useful life of 125 hours.

[10] The ZHL data of MOVES3 are in the units of g/bhp-hr.

[11] Class I lawnmower useful life of 47.9 hours and load factor of 0.33.

Industry Data Submittals

Current manufacturers of small SI non-handheld engines were contacted, and two levels of data were requested, termed "primary" and "secondary". The primary data request was for copies of final federal ABT submittals for model years covering Phase 3 compliance for small SI non-handheld nonroad engines. These data encompass Class I and II engines.

The secondary request included additional information on each engine family certified, including a listing of applications, valve technology and ownership types. Due to manufacturer schedule constraints, secondary data was not provided. As such, resolving these data by application or ownership types was not possible. The distinction of valve technology (side-valve and overhead valve), however, was identified though EPA certification data records for each engine family.

A limited number of ABT submittals for model years 2012 through 2022 were received and reviewed for the compliance evaluation. The goal of the compliance evaluation was to validate Phase 3 emission rate assumptions and identify mean industry FELs and certification useful life values. Multiple attempts were made to obtain additional submittals. However, the final response level was too small to complete a regulatory compliance evaluation. As such, no modifications to emission rate assumptions were proposed for this project.

Included in the submittals received was one from the sole manufacturer (Briggs & Stratton Corporation) that produced side-valve engines through model year 2017. An estimate of side-valve market share of Class I engine sales was calculated from this submittal based on public information sources of total market size[12] and later adjusted by Briggs & Stratton (see Table 6). The revised side-valve market share estimate provides an update to the 60 percent assumption of the MOVES3 model.

Class I Engines by Valve Location

Table 3 presents the proportion of side-valve sales by model year. It was confirmed that 2017 was the final model year for side-valve Class I engine sales as observed in EPA's public certification database.

Table 3. Side-valve Sales as a Percent of Class I Engine Sales.

Model Year	Side-valve	MOVES3 Assumption
2012 - 2017	11%	60%
2018+	0%	60%

The case of zero percent side-valve engines was modeled in MOVES3 for calendar year 2060 (to represent fully phased-in standards) for Austin County, TX and compared against the MOVES

[12] Outdoor Power Equipment Institute (OPEI) and Truck and Engine Manufacturers Association (EMA) comments to the California Air Resources Board's Proposed Amendments to the Small Off-Road Engine Regulations: Transition to Zero Emissions, November 2021.

default of 60 percent. The inventory results are summarized in Table 4. Eliminating side-valve engines results in a reduction of HC emissions by 6 percent, with an increase in NO_x emissions of 19 percent, although the net change in HC+NO_x is minimal. The HC/NO_x tradeoff observed in Table 4 is consistent with the EPA's Phase 3 compliance assumptions. The difference between the side and overhead valve cases is the HC/NO_x mass split, which is approximately retained throughout the service life. Given that MOVES3 has independent HC and NO_x temperature corrections, under in-use conditions there is a minor spatial variance in the HC and NO_x tradeoff. But the modification of the proportion of sales by valve location results in roughly equal parts lower HC and higher NO_x.

Table 4. Austin County Class I Engine Inventory (lbs./day), 2060 (July Weekday)

Pollutant	60% Side-valve	0% Side-valve	% Difference
HC	46.7	44.1	-6%
NO_x	15.4	18.4	19%
HC+NO_x	62.1	62.4	0%

Conclusions and Recommendations

The absence of a more complete analysis of compliance margins by the EPA for the Phase 3 rulemaking was unexpected. Typically, EPA estimates compliance margins for the full scope of the regulated fleet. Here the EPA examined Class I lawnmowers but did not publish compliance margins for other Class I or Class II applications (e.g., rear engine riding lawn mowers or lawn and garden tractors). Moreover, the MOVES3 modeling assumptions do not include any compliance updates to the original rulemaking assumptions and do not address the three levels of certification useful life available to manufacturers.

While an assessment of 50-state certification impacts on emission rates could not be completed, the single industry data submittal from Briggs & Stratton was sufficient to propose an update of the Class I market share between side-valve and overhead valve engines shown in Table 3. The MOVES3 model has distinct emission rates by valve location and an underlying assumption of 60 percent side-valve sales, while side-valve Class I engines have not been manufactured since 2017.

ERG recommended updating the value market share assumptions of the MOVES3 model by adjusting the engine technology fractions used as inputs to the model and programed TexN2 to modify these values on the fly when preparing input files for MOVES3 as part of a TexN2 utility run. The updated distribution of sales by valve location for Phase 3-compliant engines by model year was incorporated into the data table "nrengtechfraction" and is an improvement to the nonroad inventory. The TCEQ concurred with this recommendation. The emissions impact analysis below relied on standalone MOVES3 runs. Users of the TexN2 utility will not be aware of this change from EPA defaults because ERG updated the utility to modify a copy of the EPA default "nrengtechfraction" table.

Emissions Impact Analysis

ERG calculated the emissions impact associated with updating the side-valve market share for Class I NHH spark ignition (SI) engines meeting Phase 3 certification standards. The sales splits were incorporated into the MOVES3 model and emission results were estimated for two cases: (1) existing model defaults and (2) the revised sales split.

The following inputs were specified to illustrate the emissions inventory impacts.

Domain: 9-county Dallas-Fort Worth ozone nonattainment region[13]
Inventory year: 2023
Temporal basis: July average day (weighted average of weekday/weekend)
Nonroad sector: small SI gasoline engines
Pollutants: VOC and NO_X

EPA's current regulatory framework for small SI nonroad engines establishes five engine classes for which distinct emission standards are set. The engine classes are summarized in Table 5. The analysis only impacts Class I NHH engines; however, the inventory includes all gasoline small SI engines in order to estimate how the update impacts the sector as a whole. Accordingly, Class II NHH engine and Class III-V hand-held (HH) engine inventory results are included. Gasoline-fueled engines rated above 25 horsepower (HP) are considered large SI engines and are not part of the analysis. Gasoline engines used in recreational land and marine applications fall under separate certification and standards regimes and are also excluded.

Table 5. Certification Engine Classes for Small SI Nonroad Engines

Engine Class	Type	Engine Displacement (cc)	Power Range (HP)	
			Min	Max
Class I	NHH	< 255	3	6
Class II	NHH	≥ 255	6	25
Class III	HH	< 20	0	1
Class IV	HH	≥ 20, < 50	1	3
Class V	HH	≥ 50	3	6

Updated Sales Splits

Briggs & Stratton provided an additional review of the initial sales splits shown in Table 3 based on internal corporate information.[14] Based on their recommendation, the sales splits were amended slightly. Table 6 presents the final, adjusted sales splits of side-valve engines for Phase

[13] Nine counties of the 2015 ozone standard non-attainment region consist of Collin, Dallas, Denton, Ellis, Johnson, Kaufman, Parker, Tarrant, and Wise Counties.

[14] Briggs & Stratton was the only remaining side-valve Class I engine manufacturer when Phase 3 standards commenced. Their review included internal estimates of the size of the Class I engine market which was the denominator in developing the revised sales splits.

3 Class I engines.[15] The existing MOVESE3 default sales split is 60 percent side-valve, 40 percent overhead valve. The updated portion of side-valve engines is 12 percent of sales for model years 2012 to 2017 and zero percent thereafter. The portion of sales that are not side-valve are assigned to overhead valve placement.

Table 6. Final Side-Valve Sales as a Percent of Class I Engine Sales

Model Year	Data Analysis Plan Update	MOVES3 Assumption
2012 - 2017	12%	60%
2018+	0%	60%

Engine Technology

The sales splits were incorporated into MOVES3 by modifying the engine technology distributions. For Class I engines, the valve location is considered an engine technology distinction. The revised splits were modeled through modification of the MOVES3 data table "nrengtechfraction". These changes impact the emissions inventory because MOVES3 assigns emission rates by engine technology.

Table 7 summarizes the small SI gasoline engine technologies that have equipment population estimates greater than zero in the 2023 inventory according to MOVES3. "Phase" refers to the phase of the emission certification standard. Phase 3 standards apply to Class I and II engines. The sales splits were updated by revising the fraction of sales assigned to engine technology IDs 143 and 144. MOVES3 assumes that Class II engine sales meeting Phase 3 standards are 100 percent overhead valve, consistent with certification records indicating that side-valve Class II engine manufacturing ended with adoption of the Phase 3 certification standards.

Table 7. Active Small SI Gasoline Engine Technologies in the 2023 Texas Inventory Scenario

Class	MOVES3 Engine Technology ID	MOVES3 Description
NHH, Class I	141	Phase 2 overhead-valve, 4-stroke
	142	Phase 2 side-valve, 4-stroke
	143	**Phase 3 overhead valve, 4-stroke**
	144	**Phase 3 side-valve, 4-stroke**
NHH, Class II	127	Baseline gas 2-stroke non-handheld Class II
	128	Baseline overhead-valve, 4-stroke
	129	Baseline side-valve, 4-stroke
	130	Phase 1 overhead valve, 4-stroke
	131	Phase 1 side-valve, 4-stroke
	132	Phase 2 overhead valve, 4-stroke
	134	Phase 3 overhead-valve, 4-stroke

[15] Phase 3 certification standards commenced with model year 2012.

Class	MOVES3 Engine Technology ID	MOVES3 Description
HH, Class III	110	Phase 2 with catalyst 2-stroke Class III
HH, Class IV	119	Phase 2 gas 2-stroke handheld Class IV with Catalyst
HH, Class V	120	Phase 2 4-stroke gas
HH, Class V	125	Phase 2 gas 2-stroke handheld Class V

Emission Rate Impacts

The valve location (side or overhead) has an impact on the combustion characteristics, efficiency, and emissions from Class I small SI engines. Accordingly, MOVES3 has distinct emission rates for the different valve locations. The impacts on MOVES3 exhaust and evaporative emission rates are described below.

Exhaust Rates

As described previously, the MOVES3 exhaust emission rates are a function of accumulated hours and are defined by a zero-hour level (ZHL) and deterioration factor (DF) formula, which relies on Coefficient A, as shown in the following two equations.[16]

$$EmissionRate_{Aged} = ZHL \times DF$$

$$DF = 1 + A \times \left(\frac{CumulativeHours \times Load}{MedianLife}\right)^{0.5}$$

Table 8 presents the values for ZHL and Coefficient A for Class I engines by valve location. Phase 3 emission rate parameters were developed from a test program of engines meeting Phase 2 standards by applying engineering assumptions regarding standard effectiveness.[17, 18]

[16] Median life in hours is defined at full engine load.

[17] "Phase 3 Technology Mix, Emission Factors, and Deterioration Rates for Spark-Ignition Nonroad Non-handheld Engines at or below 19 Kilowatts for the NONROAD Emissions Inventory Model," from Phil Carlson to Docket EPA-HQ-OAR-2004-0008, March 8, 2007.

[18] "Updates to Phase 2 Technology Mix, Emission Factors, and Deterioration Rates for Spark-Ignition Nonroad Non-handheld Engines at or below 19 Kilowatts for the NONROAD Emissions Inventory Model from Phil Carlson to Docket EPA-HQ-OAR-2004-0008, March 8, 2007.

Table 8. MOVES Emission Rate Parameters by Valve Location, Class I Engines Meeting Phase 3 Standards

Pollutant	Parameter	Side-valve	Overhead Valve
HC	ZHL (g/kW-hr)	5.60	5.09
	Coefficient A	0.797	0.797
NO_x	ZHL (g/kW-hr)	1.40	1.91
	Coefficient A	0.302	0.302
CO	ZHL (g/kW-hr)	319.8	325.1
	Coefficient A	0.070	0.070
PM	ZHL (g/kW-hr)	0.24	0.05
	Coefficient A	1.753	1.753

Since there is no difference in the deterioration coefficient by valve location, exhaust inventory impacts are driven by differences in exhaust ZHL emission rates. Under the higher share of overhead valve engines in the revised sales split, the MOVES3 model estimates an increase in exhaust NO_x and a decrease in exhaust HC.[19]

Side-valve engines have poorer gas flow and a lower compression ratio which result in a reduction in efficiency, while overhead-valve engines better optimize space and allow for an increased compression ratio which leads to higher efficiency and flame temperature. Higher flame temperatures are associated with higher NO_x but lower HC emissions. Accordingly, the corresponding MOVES3 emission rates largely agree with expectations.

Evaporative Rates

When conducting MOVES modeling it was determined that modifications to the sales splits by valve location for Class I engines have an impact on evaporative emissions. As noted above, the overhead valve location allows space for a higher compression ratio and results in more efficient combustion (i.e., consumes less fuel per unit work completed). Engine efficiency in MOVES3 is specified by brake-specific fuel consumption (BSFC), the mass of fuel consumed per unit of work (hp-hours). For Phase 3 compliant Class I engines, the two BSFC rates in MOVES3 are shown in Table 9.

Table 9. MOVES3 BSFC Rates of Phase 3 Class I Engines

Engine Class, Technology	BSFC (lb./hp-hr)
Class I, Side-valve	0.921
Class I, Overhead Valve	0.781

MOVES3 estimates the volume of fuel consumed using the equation shown below. The revised sales split increasing the fraction of overhead valve engines results in less fuel consumption. This in turn impacts the MOVES "refueling vapor" and "refueling spillage" evaporative

[19] HC emission rate impacts are reported as VOC emissions in the inventory results. VOCs include hydrocarbons and oxygenated hydrocarbons which participate in atmospheric photochemical reactions.

processes, both of which are estimated on a per volume of fuel consumed basis. Accordingly, the increase in overhead valve sales fractions results in reduced evaporative VOC emissions.

$$Fuel\ Volume = \frac{BSFC \times Load \times Engine\ Rating \times Use\ Hours}{Fuel\ Density}$$

Inventory Results

Engine Populations

Table 10 summarizes the estimated small SI engine populations for both the MOVES default and updated valve location distributions. In July 2023, there are an estimated 2.7 million engines operating in the 9-county Dallas-Fort Worth ozone non-attainment region (DFW NAR). Of those, 1.2 million are Class I engines (45 % of the total). According to MOVES3, Phase 3 standards are almost fully phased-in for both Class I and Class II engines by this time – with just under 5,000 engines remaining in-use that certified to Phase 2 or earlier standards. The population impact of the update shifts approximately 657,000 Class I engines from side to overhead-valve technology within the modeling domain.

Table 10. Small Gasoline SI Engine Populations, July 2023, 9-county DFW NAR

Class	Certification Standard	Valve Location	Inventory Scenario		
			Default	Update	Scenario Difference
NHH, Class I	Phase 3	Side	734,851	77,920	-656,931
NHH, Class I	Phase 3	Overhead	489,900	1,146,832	656,931
NHH, Class I	Phase 2	All	530	530	0
Subtotal NHH, Class I			**1,225,281**	1,225,281	**0**
NHH, Class II	Phase 3	Overhead	630,528	630,528	0
NHH, Class II	Phase 2 or before	All	4,982	4,982	0
Subtotal NHH, Class II			**635,510**	635,510	**0**
HH	Phase 2		873,061	873,061	0
Total			**2,733,852**	2,733,852	**0**

VOC Emissions

Table 11 presents the exhaust VOC inventory impact. The valve location update results in an estimated 0.17 tons/day (5 percent) net reduction in Class I VOC exhaust emissions. The impact on the total small SI engine inventory is less than a tenth of 1 percent.

Table 11. Small Gasoline SI Engine Exhaust VOC (tons/day), July 2023, 9-county DFW NAR

Class	Certification Standard	Valve Location	Inventory Scenario		
			Default	Update	Scenario Difference
NHH, Class I	Phase 3	Side	1.97	0.08	-1.89
NHH, Class I	Phase 3	Overhead	1.20	2.92	1.72
NHH, Class I	Phase 2	All	0.00	0.00	0.00
Subtotal NHH, Class I			**3.17**	**3.00**	**-0.17**
NHH, Class II	Phase 3	Overhead	9.09	9.09	0.00
NHH, Class II	Phase 2 or before	All	0.08	0.08	0.00
Subtotal NHH, Class II			**9.17**	9.17	**0.00**
HH	Phase 2		11.89	11.89	0.00
Total			**24.24**	24.07	**-0.17**

Table 12 presents the evaporative VOC inventory impact. The valve location update results in an estimated 0.27 tons/day (7 percent) net reduction in Class I evaporative VOC emissions. The impact on the total small SI engine inventory is a reduction of 2 percent.

Table 12. Small Gasoline SI Engine Evaporative VOC (tons/day), July 2023, 9-county DFW NAR

Class	Certification Standard	Valve Location	Inventory Scenario		
			Default	Update	Scenario Difference
NHH, Class I	Phase 3	Side	2.49	0.15	-2.35
NHH, Class I	Phase 3	Overhead	1.66	3.74	2.07
NHH, Class I	Phase 2	All	0.00	0.00	0.00
Subtotal NHH, Class I			**4.16**	**3.89**	**-0.27**
NHH, Class II	Phase 3	Overhead	5.31	5.31	0.00
NHH, Class II	Phase 2 or before	All	0.08	0.08	0.00
Subtotal NHH, Class II			**5.38**	**5.38**	**0.00**
HH	Phase 2		2.79	2.79	0.00
Total			**12.33**	**12.06**	**-0.27**

Table 13 presents the total VOC inventory impact, combining the values presented in Table 11 and Table 12. The valve location update results in an estimated 0.44 tons/day net (6 percent) reduction in total Class I VOC. The impact on the total small SI engine inventory is a reduction of 1 percent.

Table 13. Small Gasoline SI Engine Total VOC (tons/day), July 2023, 9-county DFW NAR

Class	Certification Standard	Valve Location	Inventory Scenario		
			Default	Update	Scenario Difference
NHH, Class I	Phase 3	Side	4.47	0.23	-4.24
NHH, Class I	Phase 3	Overhead	2.86	6.65	3.79
NHH, Class I	Phase 2	All	0.00	0.00	0.00
Subtotal NHH, Class I			**7.33**	**6.89**	**-0.44**
NHH, Class II	Phase 3	Overhead	14.40	14.40	0.00
NHH, Class II	Phase 2 or before	All	0.16	0.16	0.00
Subtotal NHH, Class II			**14.56**	**14.56**	**0.00**
HH	Phase 2		14.68	14.68	0.00
Total			**36.57**	**36.12**	**-0.44**

NO_x Emissions

Table 14 presents the exhaust NO_x inventory impact of the valve location adjustment. The update results in an estimated 0.22 tons/day (18 percent) net increase in Class I NO_x emissions. The impact on the total small SI engine inventory is an increase of 4 percent.

Table 14. Small Gasoline SI Engine Exhaust NO_x (tons/day), July 2023, 9-county DFW NAR

Class	Certification Standard	Valve Location	Inventory Scenario		
			Default	Update	Scenario Difference
NHH, Class I	Phase 3	Side	0.62	0.02	-0.60
NHH, Class I	Phase 3	Overhead	0.57	1.38	0.82
NHH, Class I	Phase 2	All	0.00	0.00	0.00
Subtotal NHH, Class I			**1.19**	**1.41**	**0.22**
NHH, Class II	Phase 3	Overhead	3.65	3.65	0.00
NHH, Class II	Phase 2 or before	All	0.04	0.04	0.00
Subtotal NHH, Class II			**3.69**	**3.69**	**0.00**
HH	Phase 2		0.47	0.47	0.00
Total			**5.35**	**5.57**	**0.22**

ERG also provided the TCEQ with a detailed spreadsheet named "Deliverable 7.2 Appendix 4-28-23.xlsx" containing additional inventory results by Source Classification Code (SCC), HP bin and engine technology. There are 417 unique combinations of SCC, HP bin and engine technology in the 2023 DFW NAR gasoline small SI engine inventory.

When reviewing these results, note that MOVES3 defines independent technology groups (and associated distributions) for exhaust and evaporative emissions calculations. For example, the evaporative emissions reported by the model are not broken out by valve location. For this reason, ERG assessed total VOC emissions (exhaust plus evaporative) by valve location for Class I engines. Then the evaporative emission results were mapped to the exhaust technology groups as a post-model adjustment.[20] Exhaust, evaporative and total HC emissions, as reported above and in the detailed spreadsheet, are stratified according to exhaust technology group.

[20] This mapping is completed at the model year level in conjunction with the exhaust and evaporative technology distributions.

III. LAWN AND GARDEN EQUIPMENT ELECTRIFICATION STUDY

This section is organized into four subsections. The first subsection presents the data collection and analysis plan designed to collect the information required to account for the fraction of electrified residential L&G equipment currently operating in Texas. The next subsection summarizes the preparation and administration of the surveys to collect the required data. The following section presents the survey findings along with the data processing and analysis steps used to ensure data quality and develop the parameters needed to update the TexN2 model. The section concludes with details regarding emission calculation methods and estimated emission impacts for VOCs and NO_x for affected equipment operating in Texas.

Data Collection and Analysis Plan

The Data Collection Plan and Analysis plan developed by ERG specified the methods to be used to collect the required information from residential L&G equipment operators, as well as the supplementary data sources, data processing steps, and Quality Assurance/Quality Control (QA/QC) and validation procedures for each survey approach to ensure precise, accurate, and fully defensible equipment profiles and populations. The plan was designed to obtain reliable data, maximize cooperation and survey response rates, and provide a comprehensive data set for preparing the updated TexN2 utility data files. The plan also required the ERG team maintain strict data recording and reporting controls to ensure that no confidential information obtained during the survey tasks is released.

Emission Sources

The plan focused on collected data on the following 2- and 4-stroke gasoline-powered equipment classifications, including their specific SCC:

- 2-Stroke Rotary Tillers (< 6 hp) (residential) – 2260004015
- 2-Stroke Chain Saws (< 6 hp) (residential) – 2260004020
- 2-Stroke Trimmers/Edgers/Brush Cutters (residential) – 2260004025
- 2-Stroke Leafblowers/Vacuums (residential) – 2260004030
- 4-Stroke Lawn Mowers (residential) – 2265004010
- 4-Stroke Rotary Tillers (< 6 hp) (residential) - 2265004015
- 4-Stroke Trimmers/Edgers/Brush Cutters (residential) – 2265004025
- 4-Stroke Leafblowers/Vacuums (residential) – 2265004030
- 4-Stroke Rear Engine Riding Mowers (residential) – 2265004040
- 4-Stroke Lawn & Garden Tractors (residential) – 2265004055

Only 2-stroke gasoline-powered, 4-stroke gasoline-powered, and electric nonroad equipment were included; equipment powered with other fuels (e.g., diesel, compressed natural gas, liquefied petroleum gas, etc.) were excluded.

Data Collection Approach

The Data Collection Plan required ERG to perform a random sample survey of single-family households across Texas, with counties stratified into urban and rural groupings, to develop high-quality nonroad equipment populations based on local, county-specific data.

ERG's survey was designed to determine the number of residential L&G equipment owned and operated during the 2022 calendar year by residents of single-family detached homes, including information on fuel type (i.e., 2-stroke gasoline, 4-stroke gasoline, and electric). The survey would not request additional information regarding hours of use per year, temporal profile, etc., to keep the response time to a minimum and increase response rates. Note that for emissions benefit estimation purposes, ERG would assume electric equipment has the same activity profile and horsepower distribution as corresponding gasoline-powered units.

The survey sampling plan accounted for the tradeoffs between the number of survey categories, precision targets, and available project resources for the stratified random sample survey. The sampling plan presented below discusses the sample frames needed to establish the survey contact lists, the sample size targets, and the supplementary data needed to extrapolate findings to the state level.

Survey Sample Frame

The ideal sample frame for a survey effort would include information on all operators of targeted equipment, with no extraneous contacts (e.g., no ineligible respondents). Using a complete, accurate sample frame would therefore result in the most cost-effective survey execution. In reality, sample frames rely on different types of data sources, each with their own advantages and disadvantages.

For many years, telephone surveys have been the low-cost, highly representative "gold standard" in probability surveys. However, with more households switching from landline to mobile telephones, the coverage of landline-based random digit dialing frames has dwindled. Furthermore, because of legislation regarding how survey researchers may dial cell phones, and because of lower response rates for cell phone numbers, the cost of telephone surveys that seek coverage of cell-only households is becoming prohibitive.

Address-based sampling (ABS) offers an attractive alternative to the coverage and cost problems in the U.S. Address lists updated via the United States Postal Service (USPS) Computerized Delivery Sequence (CDS) file are often the preferred frame for household surveys in the U.S. at this time. National ABS coverage estimates vary but are high overall and nearly 100 percent in many areas. In addition, commercially available Delivery Sequence files are available with detailed Census geography down to the Census Block/Block Group, as well as zip code and Zip+4 information, which allows for detailed analysis of data among various geographic groups within the sample, along with information to accurately weight the final data.

ERG recommended drawing a stratified random sample of single-family household addresses from the CDS across all 254 counties in Texas, appending landline and cell telephone numbers to the addresses where available. This would allow survey contacts first through USPS, with follow-up calls to encourage and facilitate survey completion. The Data Collection Plan initially proposed randomly selecting 15,000 addresses from the CDS, with a projected 60-70 percent match rate for a landline or cellular telephone number (or both).

A snapshot of the target CDS data set is shown in Table 15 below.

Table 15. Texas Housing and Household information from the USPS CDS

Housing	
Housing units, July 1, 2021, (V2021)	11,869,072
Owner-occupied housing unit rate, 2017-2021	62.40%
Families and Living Arrangements	
Households, 2017-2021	10,239,341
Persons per household, 2017-2021	2.76
Computer and Internet Use	
Households with a computer, percent, 2017-2021	93.90%
Households with a broadband Internet subscription, percent, 2017-2021	86.90%

For this survey, some of the 10.24 million households (or 11.87 million housing units) would be ineligible, as some represent domiciles where no yard work is preformed (apartment buildings, other multiple dwelling units, etc.). To be as cost-effective as possible while still fully covering the population of interest (single-family dwelling units), ERG proposed restricting household selection from the Delivery Sequence file by eliminating the following listings:

- Vacant housing units
- Seasonal dwelling units
- Listings in multiple dwelling units
- P.O. Box as the only way to receive mail units

This approach restricted the sample Universe to Single-family Dwelling Units listings. The current counts on the CDS file (which is continuously updated), are shown in Table 16 below:

Table 16. State of Texas CDS Single-family Dwelling Units, January 6, 2023

Urban Counties (118)	7,310,934
Rural Counties (136)	965,578
Texas Total	**8,276,512**

Sample Size and Accuracy Targets

The accuracy of estimates derived from a random survey of a population (e.g., equipment ownership frequency) depends on the variance of the parameter across the population, and the

number of completed responses. The greater the variance, the less accurate the estimate will be for any given number of completed responses, and the more completed responses the more accurate the estimate will be.

The accuracy of survey estimates is typically expressed in terms of the result being within a given percentage range of the true value ("margin of error") for a given probability ("confidence level"). Using standard statistical assumptions, the target number of completes can be determined for a population of a given size to achieve estimates with the desired accuracy. While higher numbers of completes generally improves accuracy, for large populations the target number of completes is largely invariant with the size of the population. Conversely, if the population is relatively small, a smaller number of completes will result in estimates that achieve the desired level of accuracy. Table 17 shows the number of completes needed to obtain different levels of accuracy, for a range of population sizes based on simple random sampling.

Table 17. Target Number of Completes as a Function of Survey Population

Population Size	Number of Completed Surveys Required by Margin of Error/Confidence Level Goal	
	5%/95%	10%/95%
100	80	50
500	218	81
1,000	278	88
5,000	357	95
10,000	370	96
50,000	382	96

One must back-calculate the required sample size (i.e., the number of survey phone/email contacts) drawn from a sample frame accounting not only for total population size, desired margin of error and confidence interval, but also the anticipated non-response rate among sampled contacts (i.e., those refusing to participate plus those where no contact was achieved), and the presence of invalid records in the sample frame data set itself (i.e., sampling frame "deficiencies"). Thus, in practice the sample actually required is likely to be substantially larger than target number of completes dictated by the accuracy goals.

The number of surveys and stratifications is limited by the need to balance the precision of survey results with available data collection resources. The Data Collection Plan proposed that the study sample be stratified on a geographic basis – urban counties and rural counties, with an initial selection of 7,500 addresses in each stratum. This stratification was based on the assumption that L&G equipment ownership rates, SCC distributions (e.g., the relative number of walk-behind mowers, lawn and garden tractors, and rear-engine riding mowers), and technology mixes (i.e., gasoline vs electric) would likely be substantially different in urban and rural areas. Based upon U.S. Census definitions, all counties that are part of a Metropolitan Statistical Area were considered urban, while all other counties are considered rural. The plan

targeted 400 completed surveys within each stratum, with a confidence level of 95% for a 5% margin of error at the strata level. For state-wide estimates, basic weighting would then be applied to adjust the two strata to their proper proportions within the state total.

Surrogate Expansion Factors

Different surrogates could be used to expand the random sample survey findings to the state as a whole and then to allocate equipment populations to the county level for use in the TexN utility. For this project, the data collection plan proposed using the number of county-level single-family homes (obtained from the CDS) to expand and allocate the survey responses regarding equipment populations.

Survey Data Collection

The data elements to be collected during the surveys included the following:

- Number of gasoline- and electric-powered equipment used in 2022 year for each of the 10 equipment SCCs presented above.
- The county where single-family home is located.

Questionnaires and survey administration procedures were developed to collect the data required for the survey. Hardcopy mailers explaining the purpose of the study were to be sent in advance to all targeted respondents containing appropriate credentials, contact information, etc. to provide authenticity to the survey invitation. The introductory mailer would also include a website link allowing respondents to fill out the Qualtrics on-line survey and an email address to ask questions, confirm legitimacy of the study, or request an interviewer-conducted survey over the phone.

The specific wording of the mailer and survey questions were designed to promote participation, minimize non-response, and ensure reporting accuracy and precision. Careful wording of questions can also help avoid certain types of reporting imprecisions commonly found in equipment use surveys.

Appendix A presents the standard mailer as well as the Qualtrics survey questions.

As per the data collection plan, from 1-2 weeks after mailing, ERG would attempt to conduct a computer-assisted telephone interview with those that had not responded to the Qualtrics on-line survey. Non-respondent lists were to be updated daily and provided by ERG to call center staff. Up to four calls would be made to each household in the follow-up, with a randomization of calls between evening, weekend, and daytime attempts to maximize the probability of connecting with the respondent. Once contact was made, phone introductions would explain the purpose of the survey and clearly lay out procedures used to maintain respondent confidentiality. Questionnaire scripts would then be followed accordingly.

Data collected via phone would be entered electronically during phone interviews, with the surveyor entering a unique ID for each respondent. Notes would be kept on each call and any

respondent concerns/objections regarding specific questions would be noted and responded to with scripted answers.

Data Processing and Quality Assurance (QA)

Once surveys were completed and compiled by ERG, results would be logged in a secure file to ensure respondent confidentiality. ERG would then compile and store results in a standardized format and apply comprehensive range checks and quality assurance measures to ensure the accuracy of the data sets.

The final, quality-assured, gap-filled data set would be stored in Microsoft (MS) Excel format. It would contain, at a minimum, data files that could be linked via a unique sample identifier assigned to each respondent. ERG would then provide a complete disposition of all calls and determine the number of completed surveys, the total number of eligible respondents, and the total completion and refusal rates for each survey.

The final survey data would be merged with the corresponding surrogate data using MS Excel, with surrogates applied to equipment population data to develop county totals, and individual records maintained for each piece of equipment. Detailed comment fields would be used when processing spreadsheets to document data sources, calculation methods, and assumptions. The resulting data tables would include survey year populations by equipment type (SCC) for each county.

Administration of Surveys

ERG developed and administered the survey of residential L&G equipment following approval of the Data Collection Plan described above by the TCEQ. The following discusses the survey distribution process and response rates, details the QA steps taken to ensure the data are accurate and consistent, and presents descriptive statistics to characterize the responses, noting particular areas of uncertainty.

Survey Execution and Response

ERG initially pulled a random sample of 15,000 addresses for single-family homes across the state from the CDS, with 7,500 in “urban” counties and 7,500 in “rural” counties. ERG sent survey request information to these households via USPS the week of March 6, 2023, and responses began to be submitted the week of March 13. At this time staff began conducting follow-up phone calls to selected households to ask if they had received the survey request, encourage their participation, and conduct the survey by phone if possible. After a week of calling, it was determined the success rate for this activity was extremely low and not a cost-effective use of available resources. Table 18 summarizes the call dispositions, noting only 40 survey completions were directly attributable to phone follow-ups (for a completion rate of 0.6%).

Table 18. Call Disposition Summary

Call Disposition	Count
Answering machine	3,661
Busy signal	95
Callback	435
Complete	40
Disability compliance	2
Disconnected number	737
DO NOT CALL / ADD TO DNC LIST	22
Fax or modem line	7
Language barrier	20
No Answer	1,492
Not Qualified	22
Office/ Business	39
Refusal	641
Grand Total	**7,213**

Given the completion rate for the mailed survey alone was approximately 2.5 percent, ERG, with the approval of the TCEQ work order manager, reallocated resources from further phone calls, pulled additional random sample and sent another 15,000 mailers out the week of April 3, 2023. ERG ceased data collection May 4, 2023, after receipt of 784 submissions (including the 40 completed via phone).

Response Summary and Analysis

ERG downloaded the survey responses from the Qualtrics electronic platform and formatted and reviewed the data for analysis. First, four respondents, all located in rural counties, indicated they did not reside in single-family homes in Texas and were removed from further analysis.[21] ERG then identified five individual questions with responses of "Don't know/Refuse" and removed these from the data set as well.[22]

The following provides a breakdown of the final survey responses.

- Total eligible respondents – 780
- Response mode – 740 online, 40 phone
- Language selection – 770 English, 10 Spanish
- Response by strata – 378 urban, 402 rural
- Number of respondents owning/operating at least one piece of eligible equipment – 330 (87%) urban, 385 (96%) rural

[21] This translates to an accuracy of 99.5% for the selected sample frame (single-family homes in Texas).

[22] Three questions regarding ownership of chainsaws, one regarding tillers, and one regarding blowers.

Figure 1 displays the geographic distribution of the respondents at the county level, demonstrating broad representation across the state. **Appendix B** provides respondent counts by county.

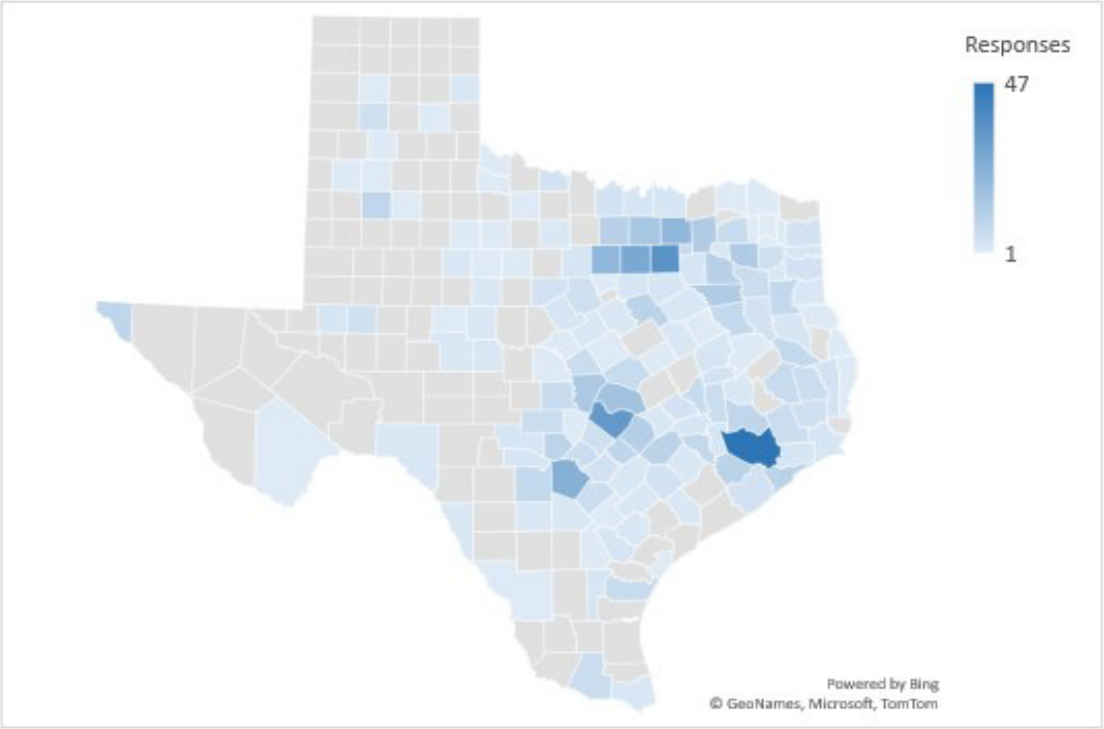


Figure 1. Geographic Distribution of Survey Respondents

Table 19 presents the total number of pieces and average number per household for each equipment type reported in the survey, broken out by urban and rural counties.

Table 19. Number of Pieces and Average Number per Household Reported in Survey

	Urban Counties		Rural Counties	
Equipment Type	**# Pcs**	**Avg #/household**	**# Pcs**	**Avg #/household**
Walk Behind Mowers	271	0.72	431	1.07
Blowers	307	0.81	360	0.90
Trimmers	305	0.81	386	0.96
Riding Lawn Mowers	40	0.11	190	0.47
Chainsaws < 6 hp	169	0.45	356	0.89
Lawn & Garden Tractors	36	0.10	151	0.38
Tillers < 6 hp	27	0.07	65	0.16
All Equipment	**1,155**	**3.06**	**1,939**	**4.82**

Figures 2 through 9 present the statewide distribution of equipment types per household, indicating that the vast majority of households have either zero or one piece per equipment type.

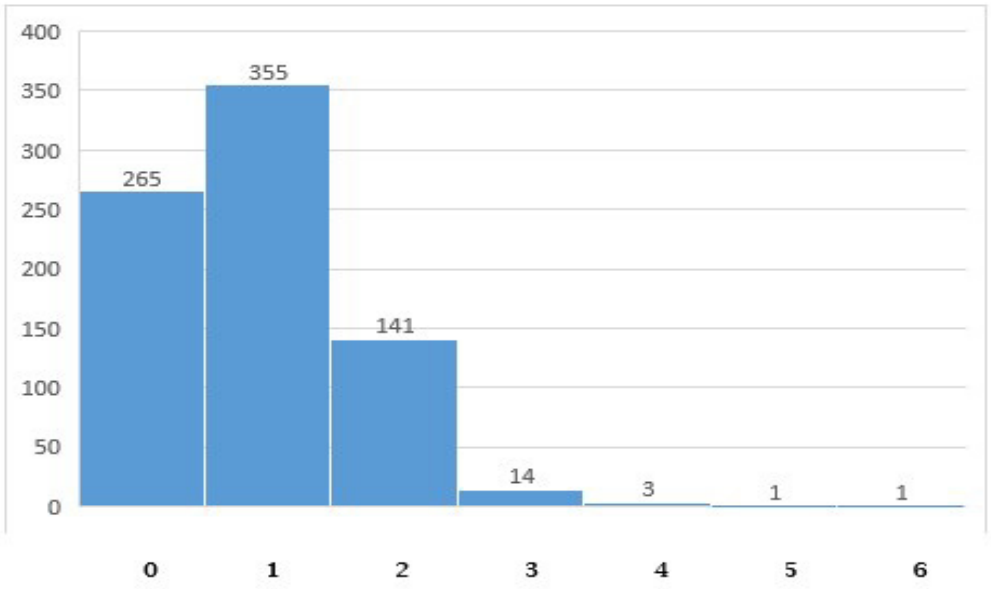


Figure 2. Number of Walk Behind Mowers/Respondent (Statewide Avg = 0.90, Max = 6)

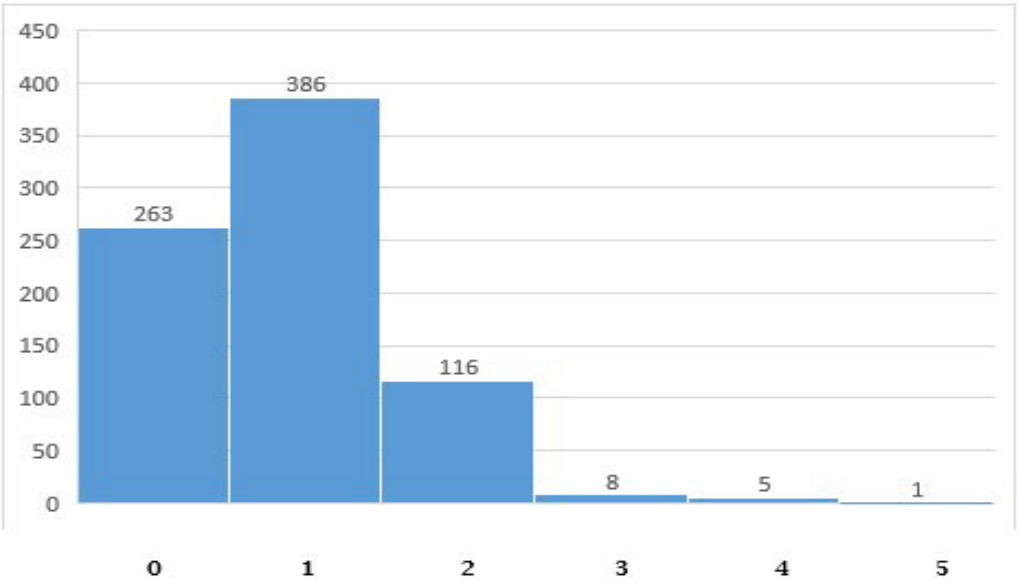


Figure 3. Number of Blowers/Respondent (Statewide Avg = 0.86, Max = 5)

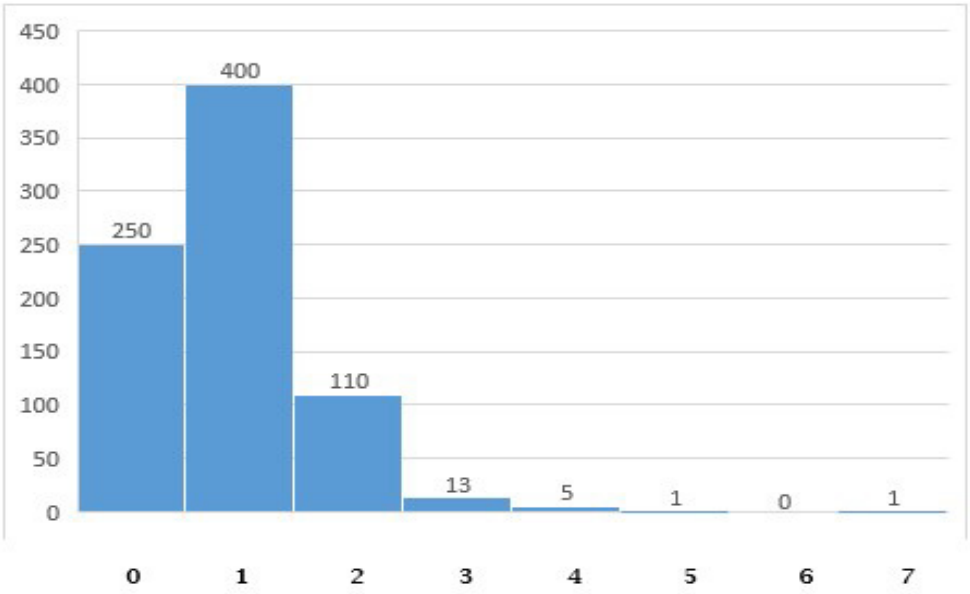


Figure 4. Number of Trimmers/Respondent (Statewide Avg = 0.89, Max = 7)

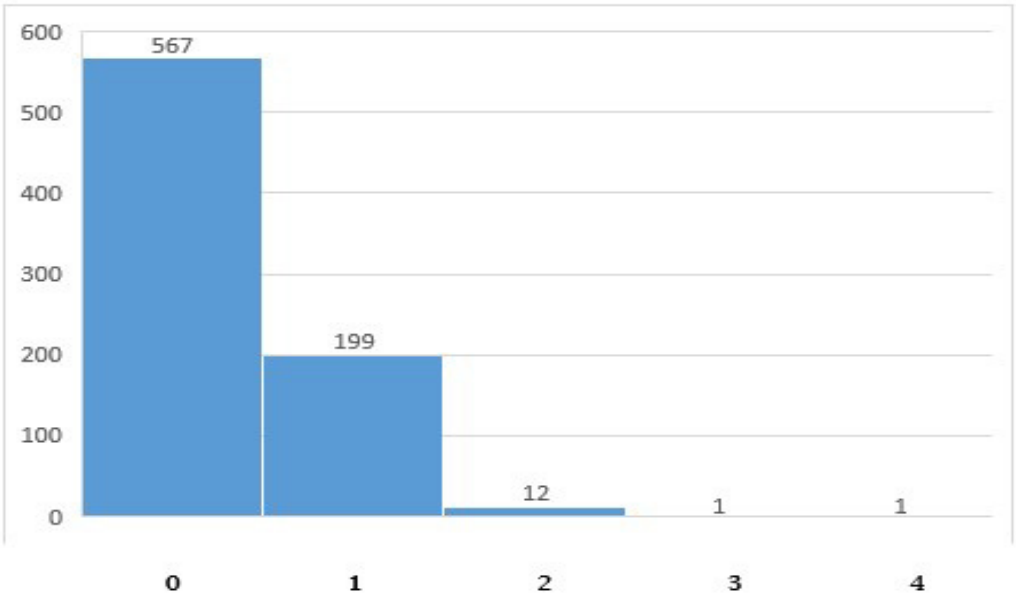


Figure 5. Number of Riding Lawn Mowers/Respondent (Statewide Avg = 0.29, Max = 4)

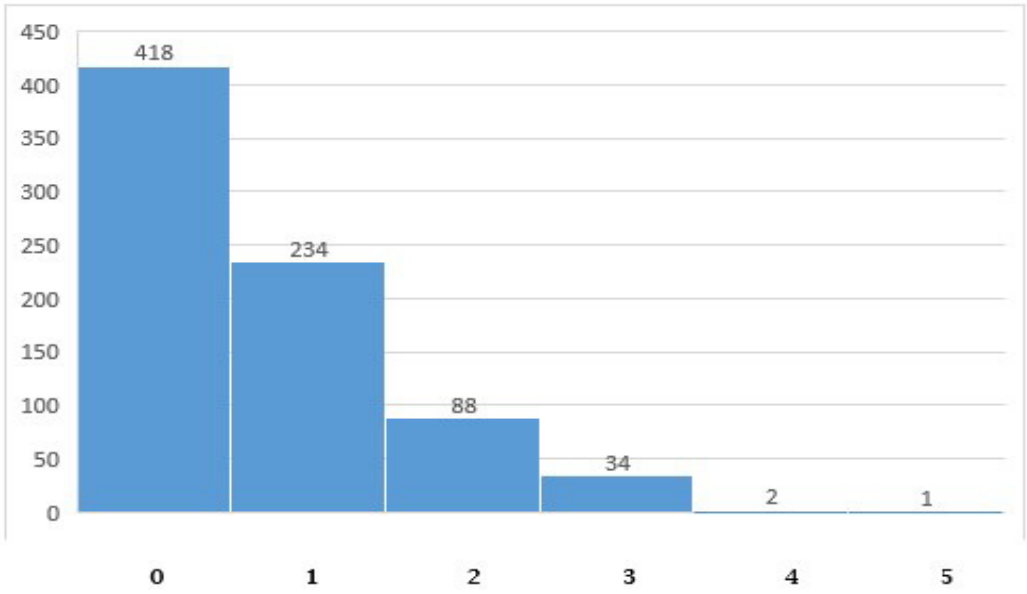


Figure 6. Number of Chainsaws < 6 hp/Respondent (Statewide Avg = 0.68, Max = 5)

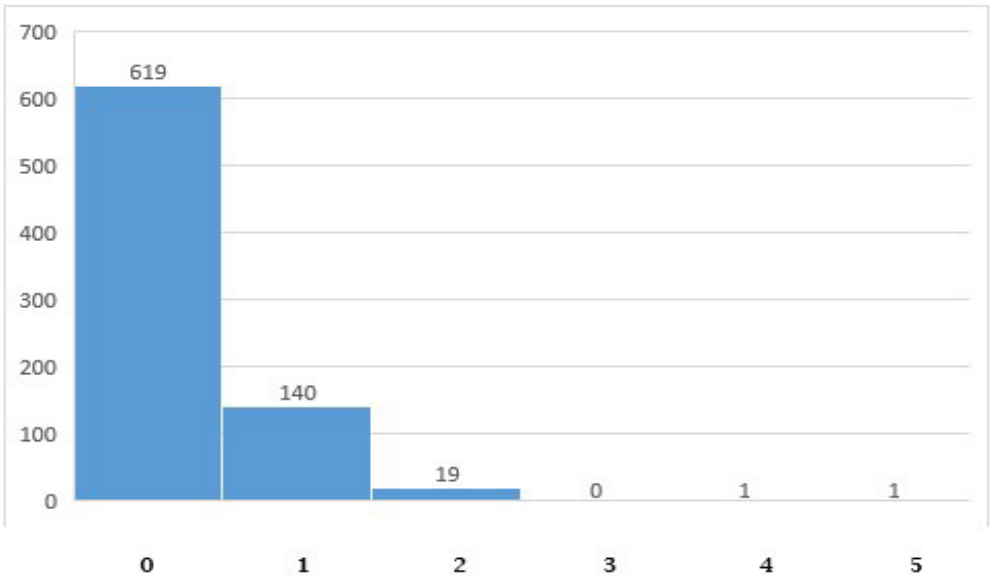


Figure 7. Number of L&G Tractors/Respondent (Statewide Avg = 0.24, Max = 5)

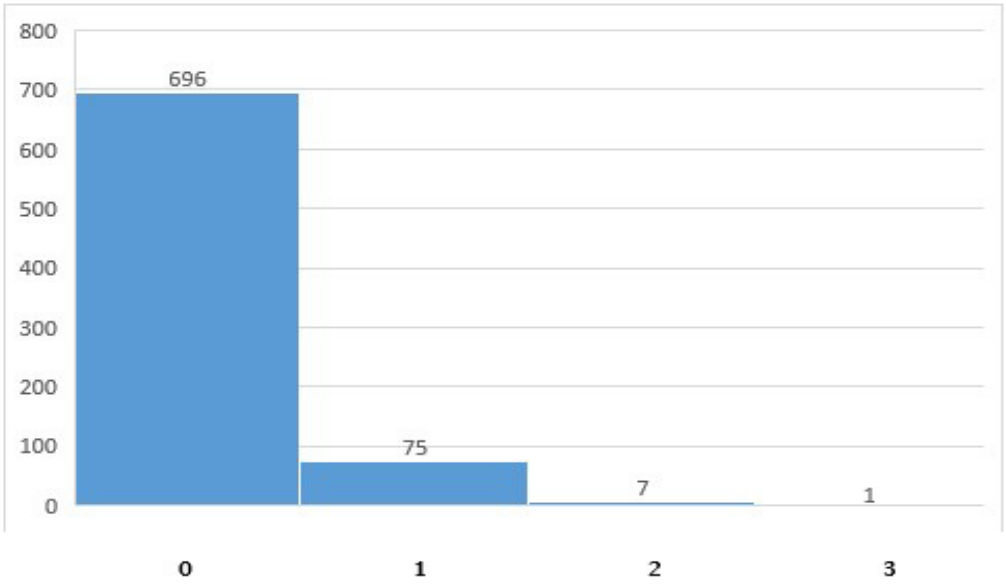


Figure 8. Number of Tillers < 6 hp/Respondent (Statewide Avg = 0.12, Max = 3)

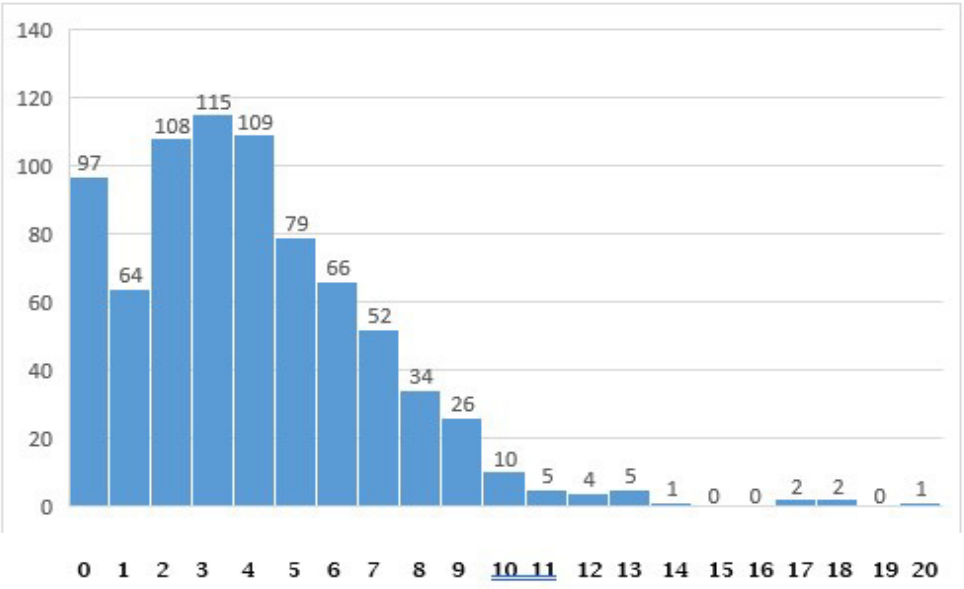


Figure 9. Number of Pieces/Respondent, All Types (Statewide Avg = 3.97, Max = 20)

Table 20 presents the electric market share for the different equipment types by geographic category and for the state as a whole.

Table 20. Reported Electric Market Share by Equipment Type

Equipment Type	Urban	Rural	State
Walk Behind Mowers	23.6%	8.8%	14.5%
Blowers	73.3%	62.8%	67.6%
Trimmers	62.6%	41.7%	50.9%
Riding Mowers	2.5%	2.6%	2.6%
Chainsaws < 6 hp	49.7%	28.7%	35.4%
Lawn and Garden Tractors	0.0%	2.0%	1.6%
Tillers < 6 hp	25.9%	20.0%	21.7%

Response Validation

ERG evaluated the responses for consistency with available information about lawn and garden equipment characteristics and use. First, ERG estimated the percent of 2-stroke vs. 4-stroke engines reported for those equipment types available with both options. Typically, small, handheld engines are predominately 2-stroke, consistent with the findings shown in Table 21. The table also presents the 2-stroke market percentage assumed in MOVES and TexN (default outputs for 2022 ozone season day in Harris County). The TexN defaults are generally consistent with the survey observations with the exception of tillers less than 6 hp.[23]

Table 21. 2-Stroke Engine Percentages Reported in the Survey vs. TexN Defaults

	Survey			TexN2
Equipment	2-stroke	4-stroke	% 2-stroke	% 2-stroke
Blowers	193	23	89%	95%
Trimmers	292	47	86%	98%
Chainsaws < 6hp	327	12	96%	100%
Tillers < 6hp	36	36	50%	14%

ERG also compared the reported population of the different equipment types relative to one another with the default distribution estimated by the TexN utility. As shown in Table 22, while walk behind mowers have the largest share of total equipment populations in both data sources, there are substantial unexplained differences (~10 percent) in the relative population of walk behind mowers and lawn and garden tractors. This discrepancy may be explained by the fact that the default MOVES/TexN equipment mix is based on national sales averages and does not reflect Texas-specific purchasing and use patterns.

[23] MOVES and TexN assume all tillers less than 3 hp are 2-stroke, and all units between 3 and 6 hp are 4-stroke. Since the survey did not request hp information it cannot be determined if the survey results are systematically biased in some way, or if the relatively high percentage of 2-strokes reported is a result of other factors (e.g., small sample size).

Table 22. Equipment Population Mix – Survey vs. TexN2 2022 Statewide Defaults

Data Source	Walk Behind Mowers	Blowers	Trimmers	Riding Lawn Mowers	Chainsaws < 6 hp	Lawn and Garden Tractors	Tillers < 6 hp
Survey (Non-electric)	34%	13%	19%	8%	15%	7%	4%
TexN2	43%	10%	18%	2%	7%	16%	4%

Next ERG compared the survey findings for urban and rural counties. Given the generally larger single-family home lot sizes in rural areas ERG expected there to be a higher percentage of households owning at least one piece of targeted equipment (consistent with responses - 87% urban vs. 96% rural), and more pieces of equipment per household (clearly seen in Table 19 for all equipment types), but a lower electric equipment market share for rural respondents (as seen in Table 20 for all but riding mowers and lawn and garden tractors).

ERG also compared the statewide electric market share estimates seen in the survey responses with estimates provided by the Truck and Engine Manufacturers Association for the national market as of late 2021 (see Table 23).[24] As seen in the table, the percent electrification nationally is substantially higher than estimated for Texas for the most prevalent lawn and garden equipment types (walk behind mowers, blowers, and trimmers). This is somewhat expected given the aggressive programs targeting small off-road engines (SORE) in California (which constitute almost 10 percent of all single-family homes in the US[25]) and elsewhere. For example, CARB has offered SORE manufacturers with ABT credits for equipment electrification for over a decade.[26]

Table 23. Electric Market Share Comparison – Statewide Texas Survey Results vs. 50-State Market Estimates from EMA (2021)

Equipment Type	Texas Survey			50-State Market
	Urban	Rural	State	
Walk Behind Mowers	23.6%	8.8%	21.2%	36%
Blowers	73.3%	62.8%	72.0%	80%
Trimmers	62.6%	41.7%	59.8%	67%
Riding Mowers	2.5%	2.6%	2.5%	3%
Chainsaws < 6 hp	49.7%	28.7%	45.3%	N/A
Lawn and Garden Tractors	0.0%	2.0%	0.7%	4%
Tillers < 6 hp	25.9%	20.0%	24.6%	N/A

[24] Comments of the Truck and Engine Manufacturers Association, California Air Resources Board Proposed Amendments to the Small Off-road Engine Regulations; Transition to Zero Emissions; Proposed Rulemaking; Initial Statement of Reasons, November 29, 2021.

[25] See https://www.infoplease.com/us/census/california/housing-statistics and https://www.statista.com/topics/5144/single-family-homes-in-the-us/#:~:text=In%20the%20United%20States%2C%20the,a%20small%20share%20is%20rented

[26] See https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2008/sore2008/soreresubfro.pdf?_ga=2.23653434.1847970254.1687113779-1882896130.1678052406.

ERG also identified respondents reporting more than two pieces of the same equipment type. Table 24 shows the number of respondents falling into this category by equipment type, and the percentage of such responses relative to the total. Such responses might merit adjustment/exclusion on the presumption that it is unlikely these units would all be used for a significant number of hours per year by an owner at their own residence.

Table 24. Number of Survey Respondents with > 2 Pieces of an Equipment Type

Equipment Type	# w/ > 2 Pcs	% w/ > 2 Pcs
Walk Behind Mowers	19	2.4%
Blowers	14	1.8%
Trimmers	20	2.6%
Riding Mowers	2	0.3%
Chainsaws < 6 hp	37	4.8%
Lawn and Garden Tractors	2	0.3%
Tillers < 6 hp	1	0.1%

As a sensitivity analysis, ERG calculated the percent equipment population reduction if respondents reporting more than two pieces of a single equipment type were excluded from the sample (see Table 25).

Table 25. Equipment Population Reduction When Excluding Respondents with > 2 Pieces of an Equipment Type

Walk Behind Mowers	Blowers	Trimmers	Riding Lawn Mowers	Chainsaws < 6 hp	Lawn and Garden Tractors	Tillers < 6 hp
7.0%	7.2%	5.2%	0.0%	12.4%	0.0%	0.0%

ERG then ran TexN2 for Harris County for an ozone season day in 2022 to estimate default NO_x and VOC emission totals for each equipment type and applied the percent population reductions in Table 25to estimate the emission impact if such respondents were excluded from the analysis. The resulting emission reductions (relative to the emission totals for all seven equipment types) were 2.3% for NO_x (0.011 tons/day or "tpd") and 4.1% for VOC (0.150 tpd).

After consultation with the TCEQ work order manager it was agreed that, regardless of speculation, there is no definitive data indicating these additional pieces of equipment are not used as reported. In addition, including these units in the statewide population projection should be consistent with EPA's approach which is based on allocating 50-state equipment sales data to the state then county levels, which may have the same type of bias associated with the survey data (i.e., an equipment sale does not necessarily imply use). For these reasons all responses were retained for emissions estimation, regardless of the number of units reported for a given equipment type.

Uncertainty Analysis

Table 26 presents the confidence intervals at the 95 percent level of significance for the average equipment ownership rates shown in Table 19, by SCC and strata. The equation for determining confidence intervals is shown below. The range between the upper bound estimate (sample mean + confidence interval) and the lower bound estimate (sample mean – confidence interval) should include the true mean of the population being sampled 95 percent of the time.

$$Confidence\ Interval = sample\ mean + (1 + significance\ level) \times standard\ deviation \times \left(\frac{1}{sample\ size}\right)^{0.5}$$

Table 26. Equipment Ownership Frequency Confidence Intervals (95% significance level), by Equipment Type and Survey Strata

Equipment Type	N	Avg #/household	Std Dev	95% Confidence Interval	Upper Bound	Lower Bound
Urban						
4-strk Walk Behind Mowers	378	0.717	0.732	0.074	0.791	0.643
2-strk Blowers	378	0.204	0.452	0.046	0.249	0.158
4-strk Blowers	378	0.013	0.114	0.012	0.025	0.002
2-strk Trimmers	378	0.272	0.506	0.051	0.324	0.221
4-strk Trimmers	378	0.029	0.168	0.017	0.046	0.012
4-strk Riding Lawn Mowers	378	0.106	0.316	0.032	0.138	0.074
2-strk Chainsaws < 6 hp	378	0.447	0.697	0.070	0.517	0.377
4-strk L&G Tractors	378	0.095	0.302	0.030	0.126	0.065
2-strk Tillers < 6 hp	378	0.032	0.190	0.019	0.051	0.013
4-strk Tillers < 6 hp	378	0.021	0.161	0.016	0.037	0.005
Rural						
4-strk Walk Behind Mowers	402	1.072	0.857	0.084	1.156	0.988
2-strk Blowers	401	0.289	0.520	0.051	0.340	0.238
4-strk Blowers	401	0.045	0.219	0.021	0.066	0.023
2-strk Trimmers	402	0.470	0.662	0.065	0.535	0.405
4-strk Trimmers	402	0.090	0.355	0.035	0.124	0.055
4-strk Riding Lawn Mowers	402	0.473	0.591	0.058	0.530	0.415
2-strk Chainsaws < 6 hp	399	0.892	0.966	0.095	0.987	0.797
4-strk L&G Tractors	402	0.376	0.635	0.062	0.438	0.314
2-strk Tillers < 6 hp	401	0.060	0.247	0.024	0.084	0.036
4-strk Tillers < 6 hp	401	0.070	0.274	0.027	0.097	0.043

VOC and NO_x Emission Impacts

ERG applied the survey findings regarding residential L&G equipment ownership rates to estimate statewide county-level populations, which in turn were used to develop updated annual and ozone season day VOC and NO_x emission estimates for each Texas county for the 2022 base year.

Statewide Equipment Population Estimation

To estimate equipment populations at the county level ERG multiplied the average number of units per single-family home for each stratum (see Table 19) by the number of single-family homes per county obtained from the CDS data set (as of January 2023, provided in **Appendix C)**. The total number of electric units were then determined by multiplying the total equipment population at the county level by the electric market shares presented in Table 20. Table 27 presents the resulting statewide equipment population totals by geographic category. **Appendix D** provides the county-level non-electric equipment totals, differentiated by 2- and 4-stroke units where applicable.

Table 27. Statewide Equipment Population Totals by Type

	Walk Behind Mowers	Blowers	Trimmers	Riding Lawn Mowers	Chainsaws < 6 hp	L&G Tractors	Tillers < 6 hp
Total # - Urban	5,241,437	5,937,716	5,899,034	773,644	3,268,645	696,279	522,210
Electric # - Urban	1,237,830	4,351,746	3,694,149	19,341	1,624,652	0	135,388
Non-electric # - Urban	**4,003,607**	**1,585,970**	**2,204,885**	**754,303**	**1,643,993**	**696,279**	**386,822**
Total # - Rural	1,035,234	866,853	927,147	456,368	861,518	362,692	156,515
Electric # - Rural	91,274	544,191	386,712	12,010	246,839	7,206	31,303
Non-electric # - Rural	**943,960**	**322,662**	**540,435**	**444,358**	**614,679**	**355,486**	**125,212**

Table 28 compares the state-level survey-based equipment population estimates to the default MOVES/TexN estimates for Texas in calendar year 2022.

Table 28. Statewide Non-Electric Equipment Population Comparison – MOVES3 Defaults vs. Survey Basis

Equipment Type	MOVES/TexN Defaults	Survey Basis	Percent Increase
4-strk Walk Behind Mowers	3,668,429	4,947,568	35%
2-strk Leaf Blowers	783,658	1,768,585	126%
4-strk Leaf Blowers	40,738	140,048	244%
2-strk Trimmers	1,544,599	2,446,098	58%
4-strk Trimmers	25,253	299,222	1085%
4-strk Riding Lawn Mowers	195,873	1,198,659	512%
2-strk Chainsaws < 6 HP	584,985	2,258,672	286%
4-strk L&G Tractors	1,338,543	1,051,766	-21%
2-strk Tillers < 6 HP	51,945	289,883	458%
4-strk Tillers < 6 HP	323,173	222,150	-31%
Total	**8,557,196**	**14,622,651**	**71%**

With the exception of 4-stroke lawn and garden tractors and 4-stroke tillers, the survey-based non-electric equipment population estimates are substantially higher than the default estimates provided by MOVES and the TexN2 utility. To investigate this discrepancy ERG compared the MOVES default estimates for the L&G equipment population in California in 2022 (12,255,758) with the corresponding survey-based estimate developed by CARB projected to the same calendar year (22,924,026). [27] [28] Although the MOVES population estimates are ostensibly for gasoline units only, the baseline population totals were developed during the 1990s when the electric market share for most L&G equipment was negligible, so the projected future year population estimates (based on Census population growth) should include electric units as well. Accordingly, the CARB total includes both gasoline and electric units for consistency, resulting in an 87 percent increase in estimated equipment counts compared to MOVES. Although not definitive, it appears that MOVES may substantially underestimate in-use L&G equipment populations compared to projections based on independent surveys.

ERG also compared the survey-based statewide residential L&G equipment population estimates for Texas in 2022 (gasoline plus electric = 27,005,293) with the corresponding survey-based estimates developed by CARB for California for 2022 (21,295,159).[29] Based on these figures Texas has approximately 27 percent more residential L&G equipment in operation than California. However, according to January 2023 CDS data, California has 13 percent more single-family homes than Texas (9,355,771 and 8,276,512, respectively). This in turn implies that Texas

[27] See https://arb.ca.gov/emfac/emissions-inventory/4767c85b6eab23d394894ca2fb0376d06229f5e3.

[28] CARB does not disaggregate residential and commercial equipment, so the MOVES totals reported here include both sectors. According to MOVES the commercial equipment component is only about 15 percent of the L&G equipment total, so any errors introduced comparing results to the residential data from Texas should be correspondingly small.

[29] See https://arb.ca.gov/emfac/emissions-inventory/4767c85b6eab23d394894ca2fb0376d06229f5e3.

has a residential L&G equipment single-family home ownership frequency roughly 50 percent higher than California. One manufacturer confirmed that recent warranty claims received from Texas for L&G equipment were substantially higher than those received from California over the same period (9,329 vs. 3,072, respectively).[30] While this does not determine the precise equipment populations in each state the large difference strongly implies higher ownership rates in Texas compared to California. Potential reasons for this difference could include single-family home lot sizes, regional variations in landscaping practices (e.g., xeriscaping frequency) and lawn/plant growing seasons, among other factors.

Statewide Emissions Estimates

The non-electric equipment counts presented in **Appendix D** were used directly in the TexN2 population lookup tables for the 2022 base year, as described in **Appendix E**. Table 29through 32 present the annual and ozone season day emissions for VOC and NO_x by equipment type, for the prior TexN defaults as well as for the survey-based equipment population updates. The net change in emissions at the equipment type level corresponds to the relative change in total equipment population, as shown in Table 28. The QA measures performed to ensure these estimates are calculated correctly are also presented in **Appendix E**

Table 29. Statewide Residential Non-Electric L&G Equipment Annual NO_x Emission Estimates (Tons/Year 2022)

Equipment Type	TexN2 Baseline	Survey Update	Net Change
4-strk Walk Behind Mowers	289	391	102
2-strk Leaf Blowers	26	58	32
4-strk Leaf Blowers	3	11	8
2-strk Trimmers	40	64	23
4-strk Trimmers	2	19	18
4-strk Riding Lawn Mowers	57	349	293
2-strk Chainsaws < 6 HP	29	111	82
4-strk L&G Tractors	759	598	(160)
2-strk Tillers < 6 HP	2	12	10
4-strk Tillers < 6 HP	24	17	(8)
Total	**1,231**	**1,629**	**399**

[30] Personal communication with Briggs and Stratton technical staff, May 2023.

Table 30. Statewide Residential Non-Electric L&G Equipment NO_x Ozone Season Day Emission Estimates (Tons/Day 2022)

Equipment Type	TexN2 Baseline	Survey Update	Net Change
4-strk Walk Behind Mowers	0.74	1.00	0.26
2-strk Leaf Blowers	0.07	0.16	0.09
4-strk Leaf Blowers	0.01	0.03	0.02
2-strk Trimmers	0.11	0.18	0.07
4-strk Trimmers	0.00	0.05	0.05
4-strk Riding Lawn Mowers	0.15	0.90	0.75
2-strk Chainsaws < 6 HP	0.06	0.23	0.17
4-strk L&G Tractors	1.95	1.53	(0.41)
2-strk Tillers < 6 HP	0.01	0.03	0.03
4-strk Tillers < 6 HP	0.06	0.04	(0.02)
Total	**3.16**	**4.2**	**1.00**

Table 31. Statewide Residential Non-Electric L&G Equipment Annual VOC Emission Estimates (Tons/Year 2022)

Equipment Type	TexN2 Baseline	Survey Update	Net Change
4-strk Walk Behind Mowers	2,166	2,925	758
2-strk Leaf Blowers	629	1,420	791
4-strk Leaf Blowers	21	72	51
2-strk Trimmers	990	1,568	578
4-strk Trimmers	15	179	164
4-strk Riding Lawn Mowers	314	1,943	1,628
2-strk Chainsaws < 6 HP	890	3,434	2,544
4-strk L&G Tractors	3,289	2,600	(690)
2-strk Tillers < 6 HP	48	269	221
4-strk Tillers < 6 HP	189	131	(59)
Total	**8,551**	**14,539**	**5,988**

Table 32. Statewide Residential Non-Electric L&G Equipment VOC Ozone Season Day Emission Estimates (Tons/Day 2022)

Equipment Type	TexN2 Baseline	Survey Update	Net Change
4-strk Walk Behind Mowers	6.49	8.74	2.25
2-strk Leaf Blowers	1.89	4.26	2.37
4-strk Leaf Blowers	0.06	0.22	0.16
2-strk Trimmers	2.91	4.60	1.69
4-strk Trimmers	0.04	0.53	0.49
4-strk Riding Lawn Mowers	0.97	5.97	5.00
2-strk Chainsaws < 6 HP	2.00	7.71	5.71
4-strk L&G Tractors	9.98	7.85	(2.13)
2-strk Tillers < 6 HP	0.14	0.79	0.65
4-strk Tillers < 6 HP	0.56	0.39	(0.18)
Total	**25.06**	**41.06**	**16.00**

County-level emissions breakouts were provided to the TCEQ in electronic format under Deliverable 4.2.

Using the updated annual emissions estimates presented in Tables 29 and 31, ERG estimated the potential impact of survey sampling uncertainty. Table 33 presents the difference in annual emissions between the upper and lower bound equipment ownership frequencies shown in Table 26 for the 2022 calendar year. At the state level, the uncertainty in VOC and NO_x emissions are estimated to be approximately +/- 20 percent of the values output by the updated TexN2 model, at the 95 percent significance level.

Table 33. Statewide Annual Emission Uncertainty Estimation, 95 Percent Significance Level (Tons/Year 2022)

Equipment Type	Updated VOC	Updated NOx	+/- Interval VOC	+/- Interval NOx
Urban				
4-strk Walk Behind Mowers	2,367	316	244	33
2-strk Blowers	1,196	49	268	11
4-strk Blowers	50	7	43	6
2-strk Trimmers	1,277	52	239	10
4-strk Trimmers	127	14	74	8
4-strk Riding Lawn Mowers	1,223	220	368	66
2-strk Chainsaws < 6 hp	2,499	81	393	13
4-strk L&G Tractors	1,721	396	551	127
2-strk Tillers < 6 hp	215	9	130	6
4-strk Tillers < 6 hp	91	12	70	9

Equipment Type	Updated VOC	Updated NOx	+/- Interval VOC	+/- Interval NOx
All Equipment - Urban	**10,765**	**1,156**	**2,379**	**288**
Rural				
4-strk Walk Behind Mowers	558	75	44	6
2-strk Blowers	224	9	39	2
4-strk Blowers	22	3	11	2
2-strk Trimmers	291	12	40	2
4-strk Trimmers	52	6	20	2
4-strk Riding Lawn Mowers	720	130	88	16
2-strk Chainsaws < 6 hp	934	30	99	3
4-strk L&G Tractors	879	202	145	33
2-strk Tillers < 6 hp	54	2	22	1
4-strk Tillers < 6 hp	40	5	15	2
All Equipment - Rural	**3,774**	**474**	**523**	**68**
All Equipment – Urban + Rural	***14,539***	***1,629***	***2,902***	***356***

Emissions Forecasting and Back-Casting

The survey of residential L&G equipment ownership allowed ERG to develop equipment population and emission estimates for the 2022 calendar year. ERG forecast the 2022 base year non-electric equipment populations in TexN2 to future years using the same growth factors included in MOVES3 for the targeted SCCs. ERG assumed the 2022 electrification levels from the survey are constant into the future, which is a conservative assumption as electric sales are likely to increase across most/all SCCs.[31]

Back-casting equipment populations is more challenging since electric equipment market share has generally increased over time, as shown for key equipment categories in Figures 10 through 13.[32]

[31] Note two factors regarding future electric market share projections: 1) the available sales trend data (shown in Figures 10 - 13) is at the national level overestimates electric market share relative to Texas, and 2) it is likely that electric market share will max out at some unknown level (but less than 100 percent) in the future, with maximums varying by equipment type. Given these uncertainties, ERG recommended capping future electric equipment market shares at 2022 levels.

[32] Outdoor Power Equipment Institute (OPEI) and Truck and Engine Manufacturers Association (EMA) comments to the California Air Resources Board's Proposed Amendments to the Small Off-Road Engine Regulations: Transition to Zero Emissions, Figures 5-1 through 5-4, November 2021. Number of gasoline units are on the left axis, percent ZEE sales on the right axis.

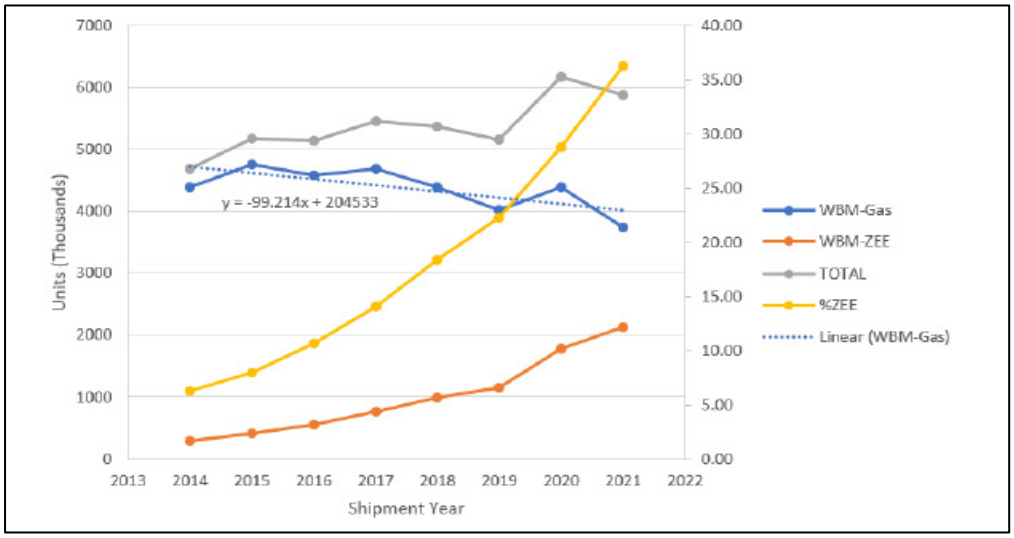


Figure 10. 50-State Residential Walk Behind Mower (WBM) Gasoline and Zero Emission Equipment (ZEE) Sales

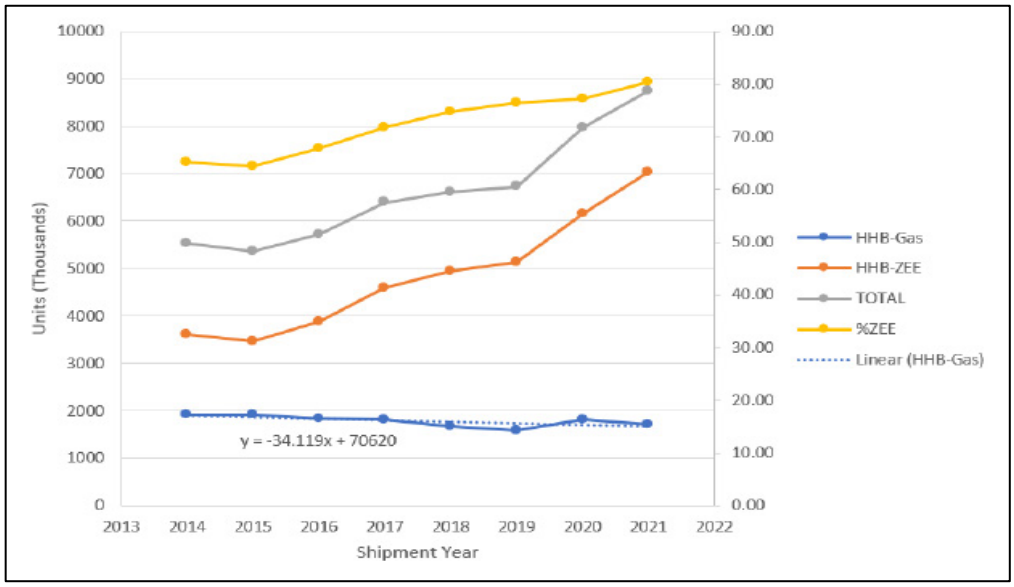


Figure 11. 50-State Residential Handheld Leaf Blower (HHB) Gasoline and Zero Emission Equipment (ZEE) Sales

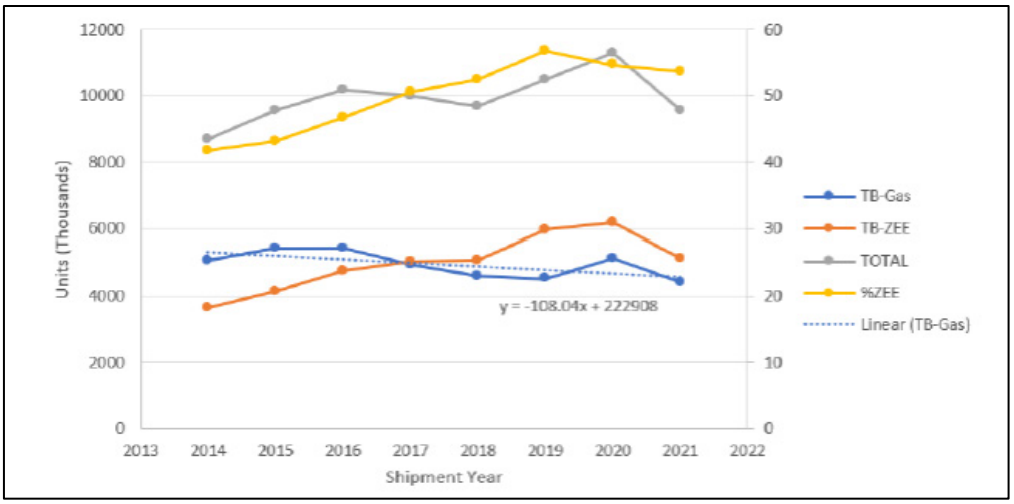


Figure 12. 50-State Residential Handheld Trimmer/Brushcutter (TB) Gasoline and Zero Emission Equipment (ZEE) Sales

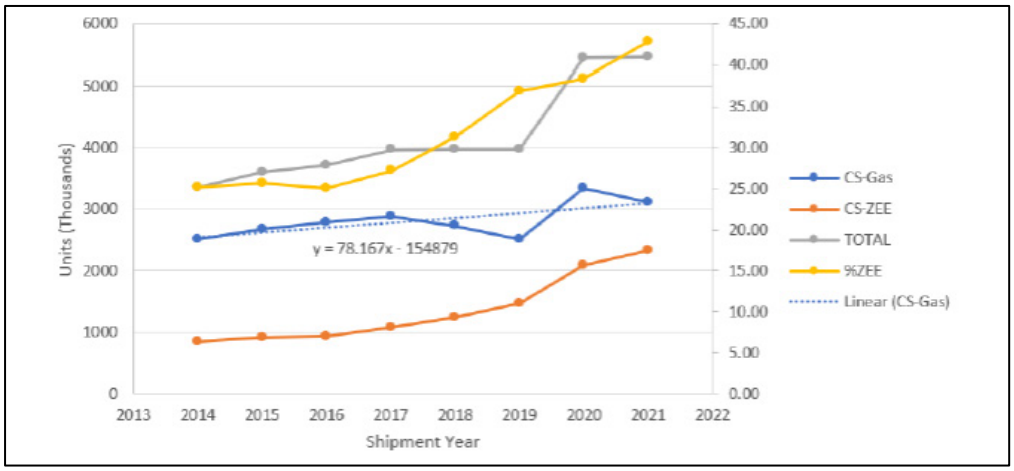


Figure 13. 50-State Residential Handheld Chainsaw (CS) Gasoline and Zero Emission Equipment (ZEE) Sales

To account for changing electrification fractions in the past ERG considered the OPEI trends shown in the above figures and adopted the following assumptions to adjust the TexN2 equipment populations prior to the 2022 calendar year.

- Growth adjustments will be the same for all hp bins within an SCC.
- Electric sales for tillers, walk behind mowers, rear engine riding mowers, and L&G tractors all began in 2011.
    - Total units will be back-casted using EPA MOVES3 default growth factors, with ERG subtracting off the electric market share component.

  - ERG will linearly increase the electric population starting in 2011 to the surveyed 2022 levels and hold 2022 levels constant into the future.
- Electric blower sales were 65% of all blower sales until 2014, at which point they will increase linearly to survey levels in 2022 and will stay at that level thereafter.
- Electric trimmer sales were 40% of all trimmer sales until 2014, at which point they will increase linearly to survey levels in 2022 and will stay at that level thereafter.
- Electric chainsaw sales were 25% of all blower sales until 2014, at which point they will increase linearly to survey levels in 2022 and will stay at that level thereafter.

IV. CONCLUSIONS AND RECOMMENDATIONS

A limited number of compliance submittals were received and reviewed, although the final response was too small to complete an emissions impact evaluation for regulatory compliance. However, industry response was sufficient to update the market share between side-valve and overhead valve engines, which in turn impacts emission rates for many small SI engines. Updating the valve location mix in the TexN2 utility results in a 1 percent reduction in small SI engine VOC emissions, and a 4 percent increase in NO_x emissions for the 2023 calendar year.

The residential L&G equipment population survey resulted in responses quite close to the targeted completion rates, with broad representation across the state. The responses were validated demonstrating general consistency with available information on L&G equipment characteristics and use. The updated survey-based non-electric equipment population estimates were substantially higher (71 percent) than the default population estimates assumed by the current TexN2 utility. Population updates resulted in a statewide VOC increase of 16 tons per ozone season day (64 percent), and a NO_x increase of 1 ton per day (32 percent) for the 2022 calendar year.

Recommendations for further research include:

- Investigate the source of the substantial discrepancy between the survey-based and MOVES3-based residential L&G equipment population estimates.
- Develop detailed projections of electric market shares by SCC beyond 2022. This could include regressions based on prior sales data and/or econometric projections accounting for anticipated demand changes.
- Conduct data collection through surveys and/or field observations to update/refine residential L&G activity estimates, which are currently based on national averages. Studies may attempt to differentiate activity by region of state as well as the urban vs. rural distinction.

Appendix A – L&G Equipment Survey Mailer and questionnaire

The following presents the mailer distributed to L&G survey targets, provided in English and Spanish.

ERG: ATTN: TCEQ Nonroad Survey
561 Virginia Road, Building 4 – Suite 300,
Concord, MA 01742

[Merged Name]
[Merged Address]
[Merged Town], TX [Merged Zip]

Texas Residents:

Eastern Research Group, Inc. (ERG) is currently conducting a study on behalf of the Texas Commission on Environmental Quality (TCEQ). We are asking residents of single-family homes in Texas to complete a short online survey about their lawn and garden equipment use in the past year. It is important to respond even if you do not use this equipment! The survey should take less than 5 minutes to complete, and the information collected will improve our understanding of the sources of air emissions across the state. Your responses will be kept confidential – only county-wide equipment counts will be shared with the TCEQ.

Take the survey online at: www.TCEQsurvey2023.com
Use survey code: [Merged Access Code]

The survey is available in both English and Spanish. If you need assistance completing the online survey, please email us at TCEQsurvey@erg.com. If you have questions regarding the study, please email the TCEQ project manager, Cody McClain, at Cody.McClain@tceq.texas.gov.

Please note that you may receive a call within 1-2 weeks to complete the survey over the phone if your household is unable to complete it online.

Thank you for your assistance.

Scan this QR code to take the survey on your mobile device!

A los residentes del Texas:

Actualmente, Eastern Research Group, Inc. (ERG) está llevando a cabo un estudio en nombre de la Comisión de Calidad Ambiental del Estado de Texas (Texas Commission on Environmental Quality, TCEQ). Por ello, estamos pidiendo a los residentes de viviendas unifamiliares en Texas que completen una breve encuesta en línea sobre el uso de equipos de jardinería y mantenimiento del césped durante el último año. ¡Es importante responder la encuesta incluso si no utiliza estos equipos! Completar la encuesta debería tomarle menos de 5 minutos y la información recopilada mejorará nuestra comprensión de las fuentes de emisiones atmosféricas en todo el estado. Sus respuestas se mantendrán confidenciales; solo se compartirán con la TCEQ los recuentos de los equipos de todo el condado.

Complete la encuesta en línea en: www.TCEQsurvey2023.com
Utilice el código de la encuesta: [Merged Access Code]

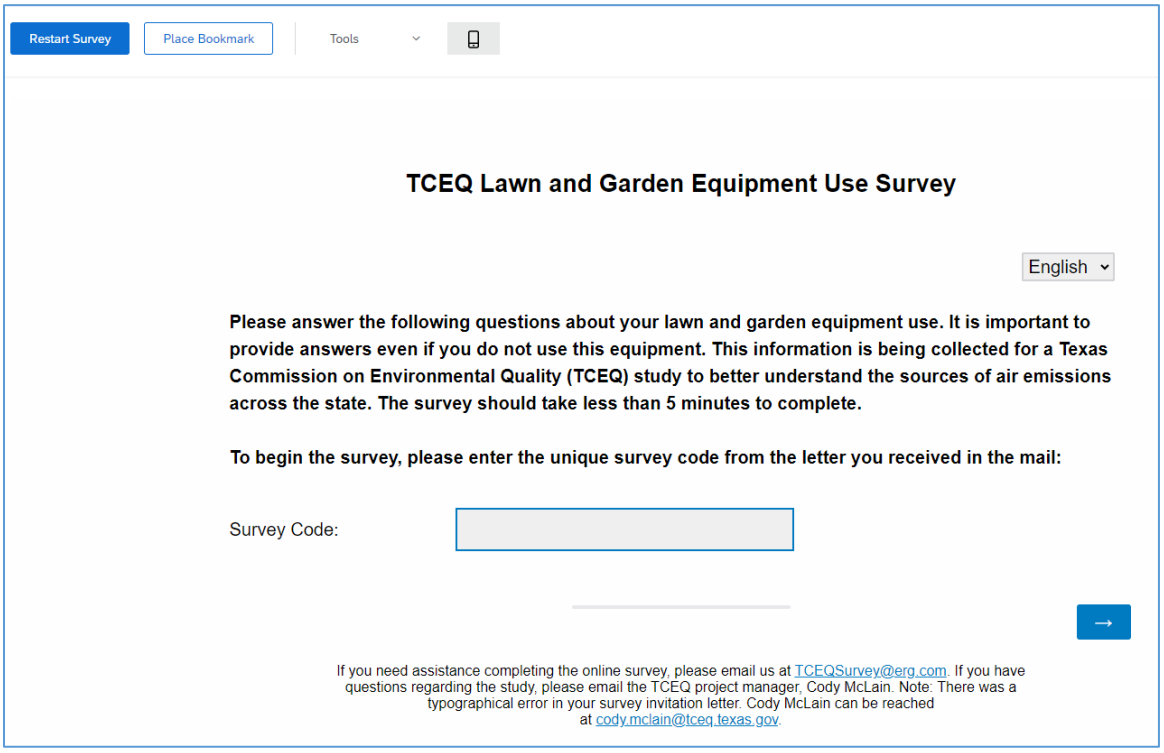
La encuesta está disponible tanto en inglés como en español. Si necesita ayuda para completar la encuesta en línea, envíenos un correo electrónico a TCEQsurvey@erg.com. Si tiene preguntas sobre el estudio, envíe un correo electrónico al gerente de proyectos de la TCEQ, Cody McClain, a la dirección Cody.McClain@tceq.texas.gov.

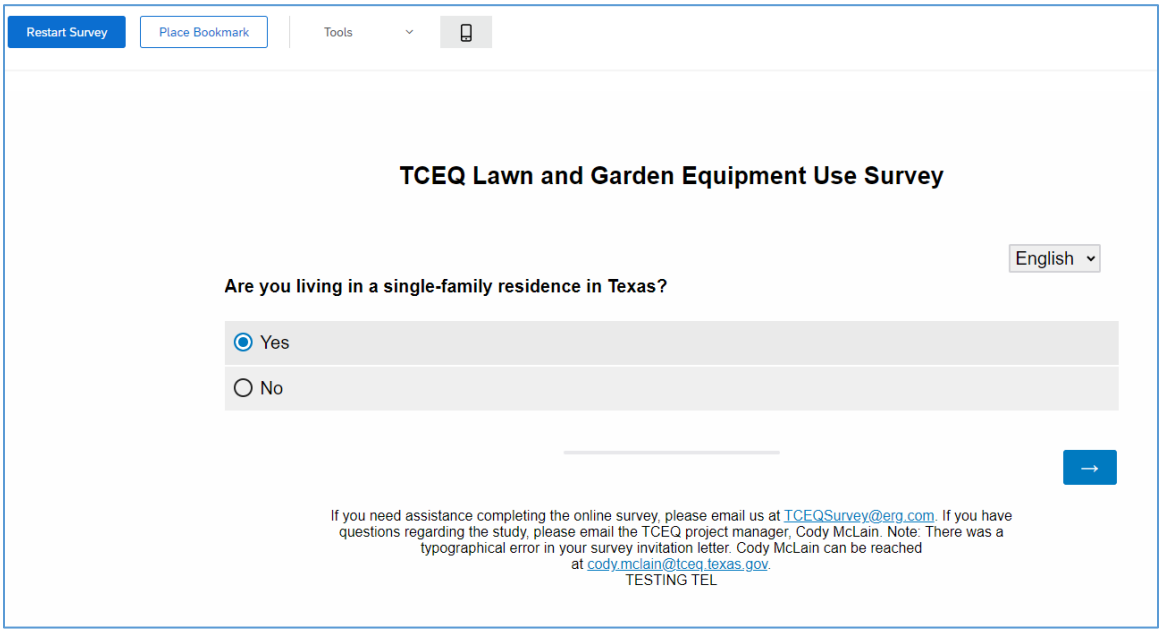
Tenga en cuenta que puede recibir una llamada dentro de 1 a 2 semanas para completar la encuesta por teléfono si su hogar no puede completarla en línea.

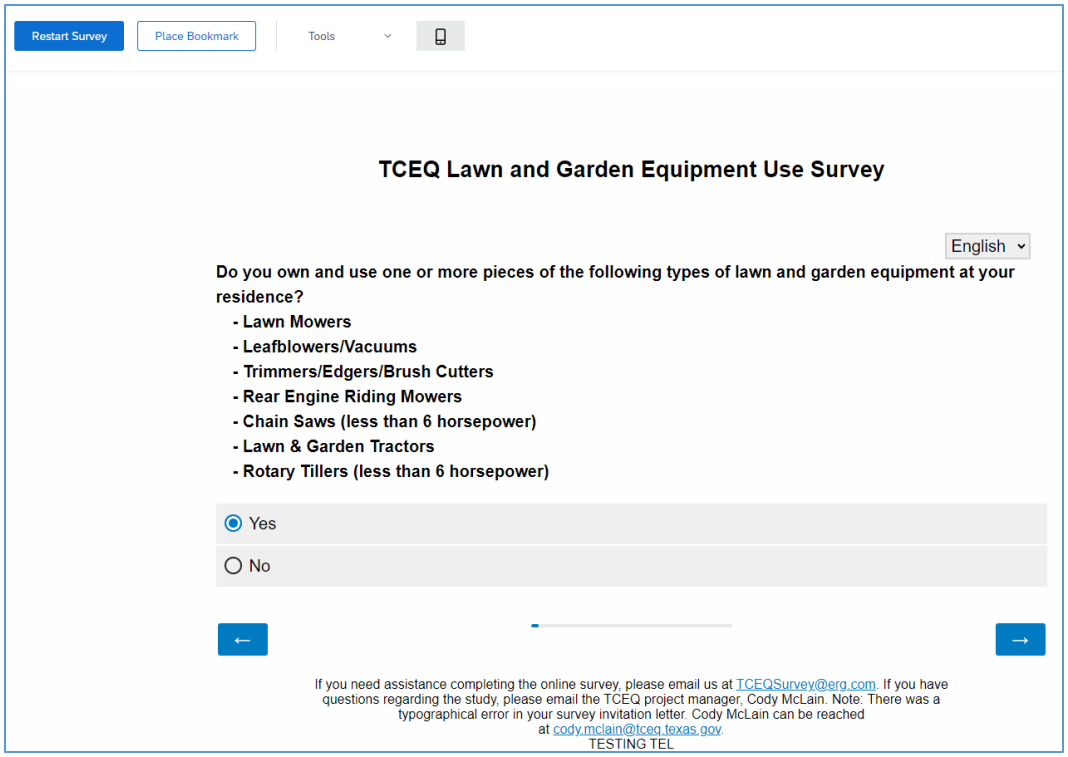
Gracias por su colaboración.

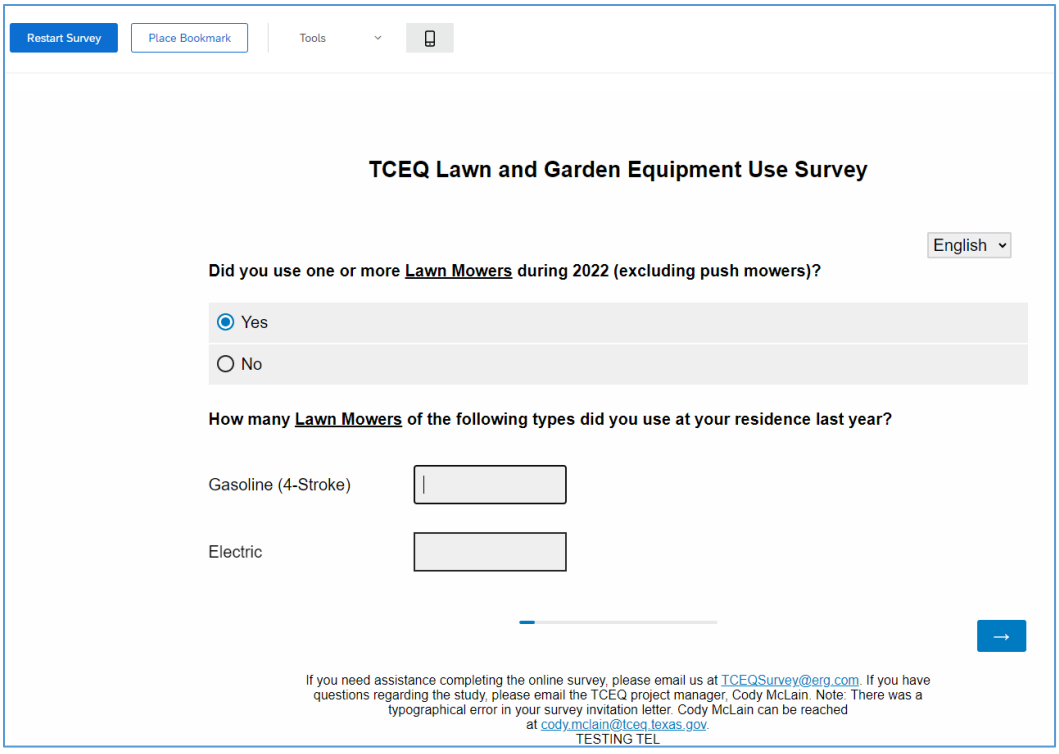
¡Escanee este código QR para completar la encuesta en su dispositivo móvil!

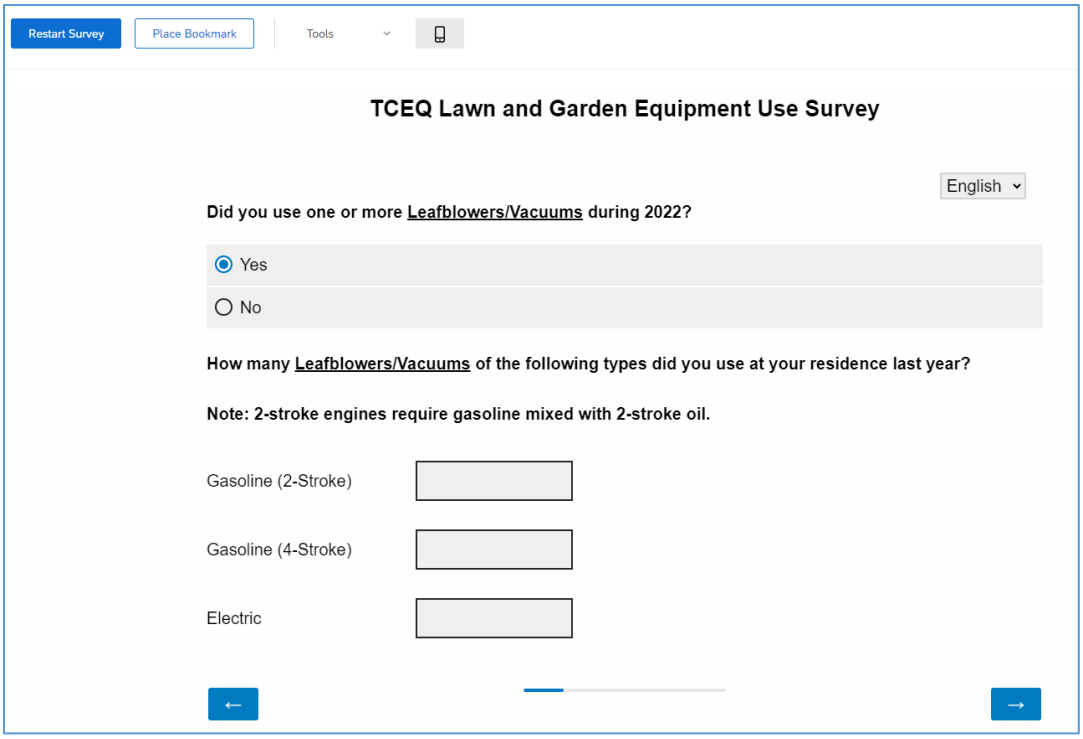
The following screenshots present the English version of the L&G equipment survey questions included in Qualtrics. Spanish text was also available by selecting the language drop-down selection on the Introduction screen.

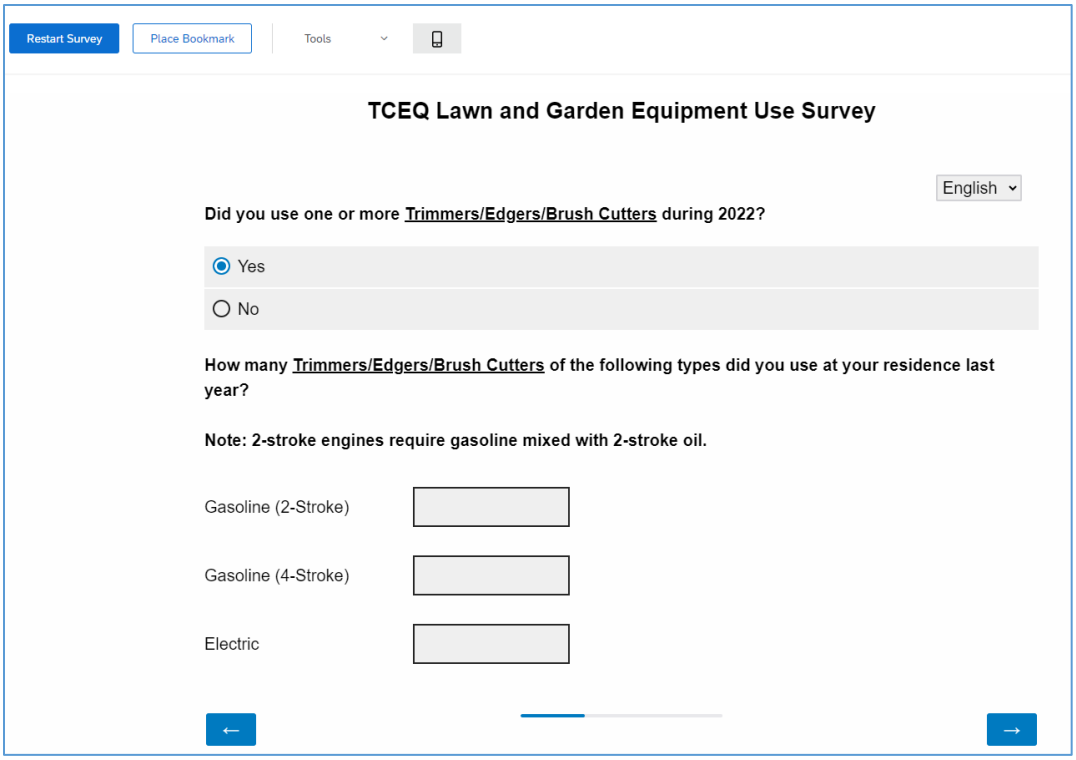


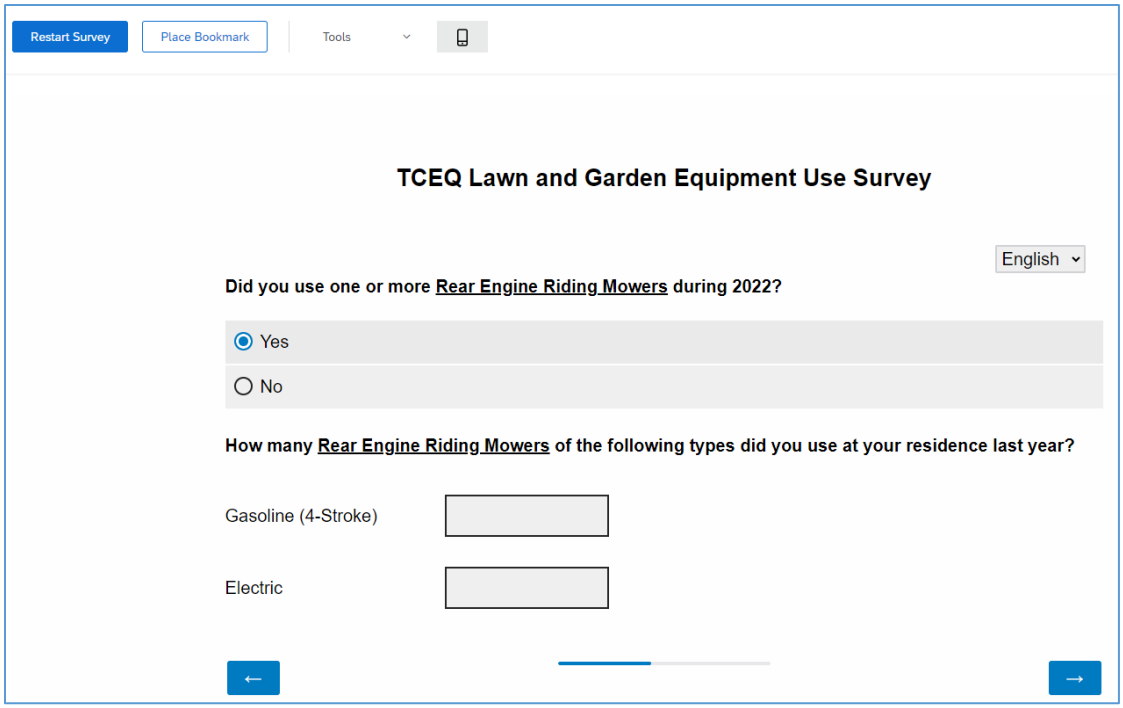


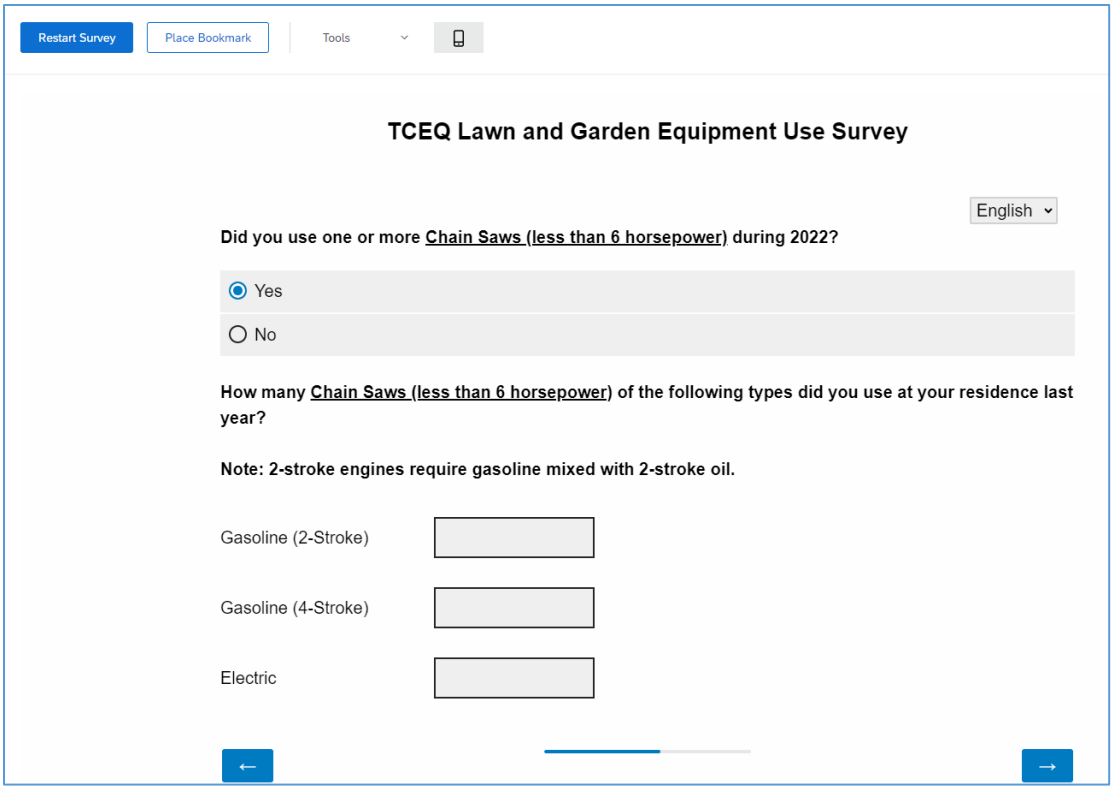

Restart Survey
Place Bookmark
Tools
TCEQ Lawn and Garden Equipment Use Survey
English
Do you own and use one or more pieces of the following types of lawn and garden equipment at your residence?
- Lawn Mowers
- Leafblowers/Vacuums
- Trimmers/Edgers/Brush Cutters
- Rear Engine Riding Mowers
- Chain Saws (less than 6 horsepower)
- Lawn & Garden Tractors
- Rotary Tillers (less than 6 horsepower)
Yes
No
←
→
If you need assistance completing the online survey, please email us at TCEQSurvey@erg.com. If you have questions regarding the study, please email the TCEQ project manager, Cody McLain. Note: There was a typographical error in your survey invitation letter. Cody McLain can be reached at cody.mclain@tceq.texas.gov.
TESTING TEL

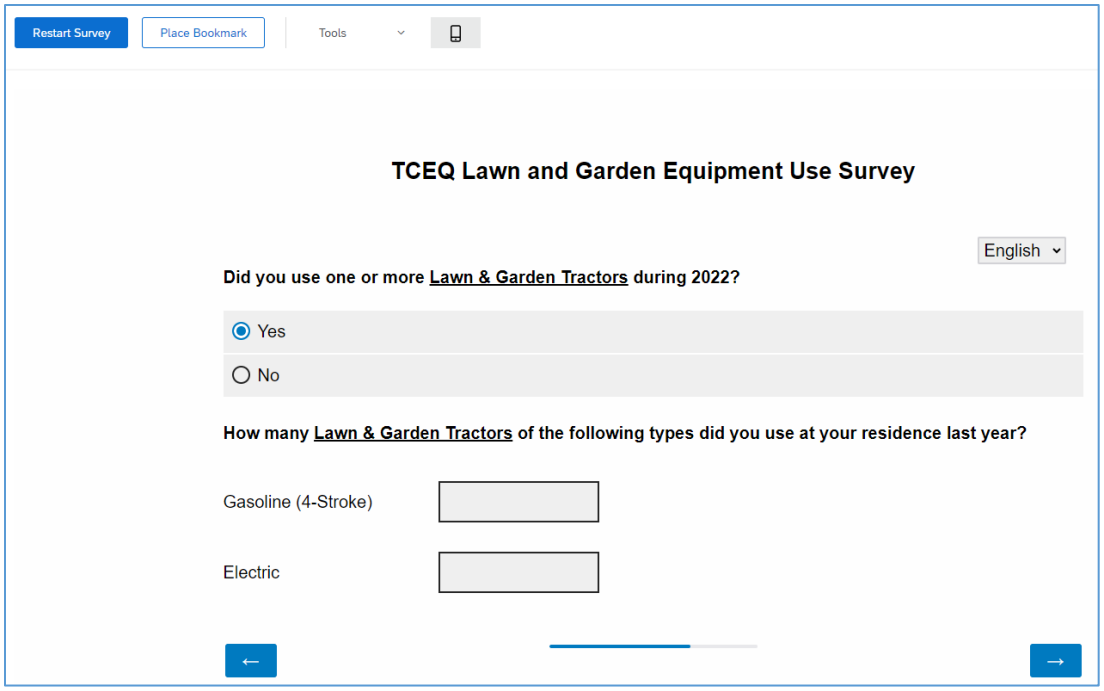

Restart Survey
Place Bookmark
Tools
TCEQ Lawn and Garden Equipment Use Survey
English
Did you use one or more Lawn Mowers during 2022 (excluding push mowers)?
Yes
No
How many Lawn Mowers of the following types did you use at your residence last year?
Gasoline (4-Stroke)
Electric
→
If you need assistance completing the online survey, please email us at TCEQSurvey@erg.com. If you have questions regarding the study, please email the TCEQ project manager, Cody McLain. Note: There was a typographical error in your survey invitation letter. Cody McLain can be reached at cody.mclain@tceq.texas.gov.
TESTING TEL

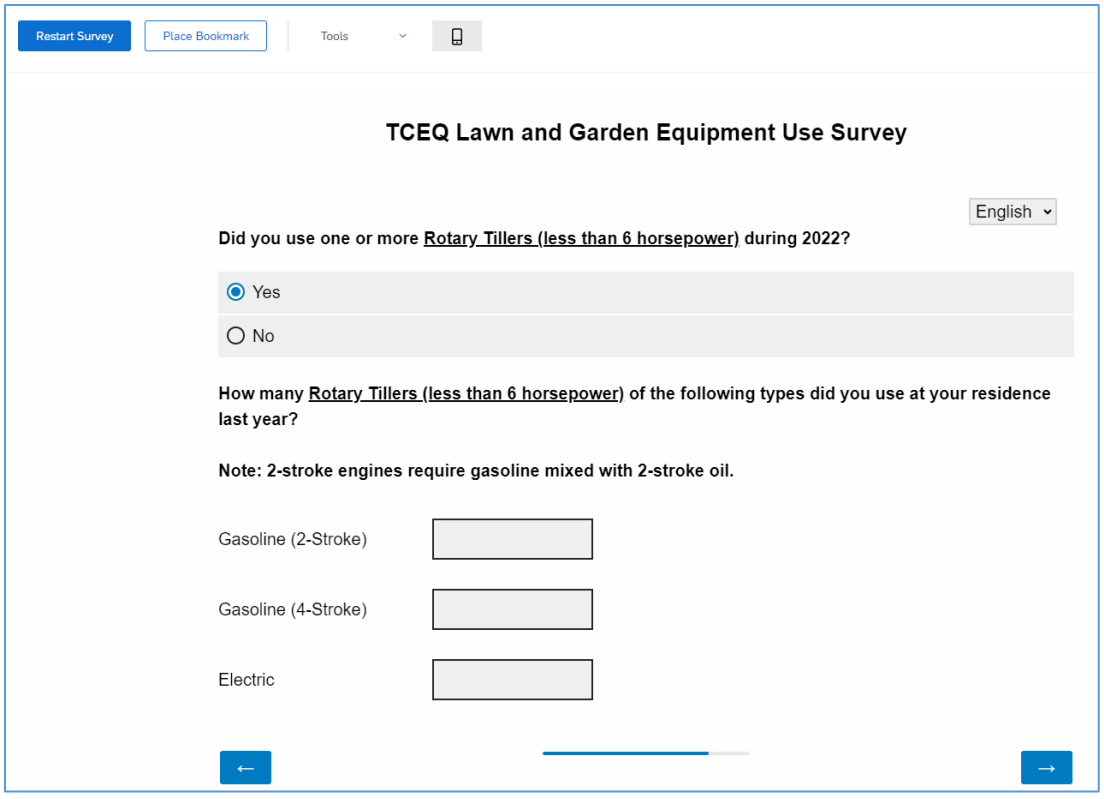

Restart Survey
Place Bookmark
Tools
TCEQ Lawn and Garden Equipment Use Survey
English
Did you use one or more Leafblowers/Vacuums during 2022?
Yes
No
How many Leafblowers/Vacuums of the following types did you use at your residence last year?
Note: 2-stroke engines require gasoline mixed with 2-stroke oil.
Gasoline (2-Stroke)
Gasoline (4-Stroke)
Electric

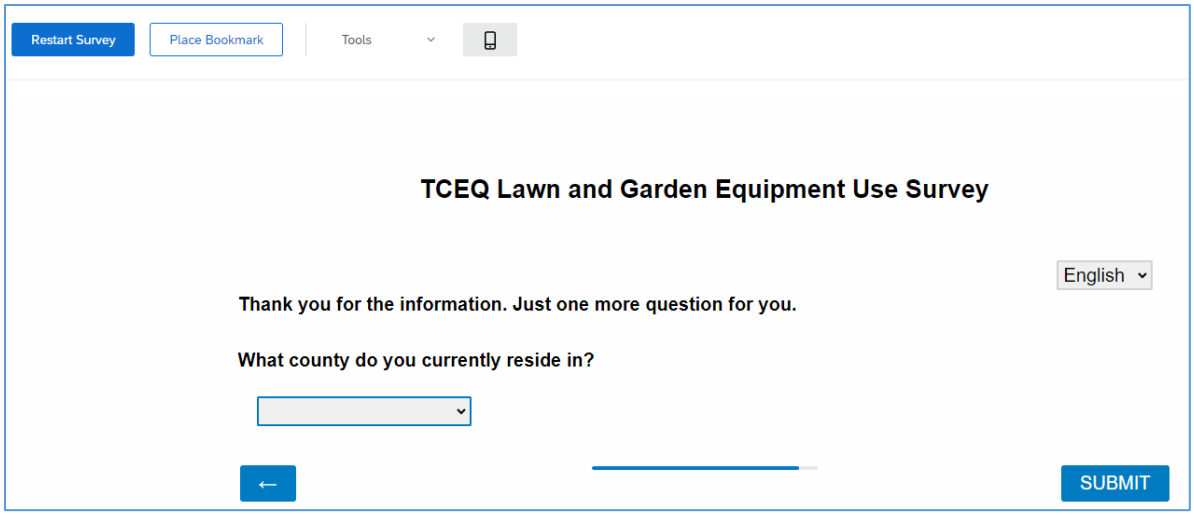

Restart Survey
Place Bookmark
Tools
TCEQ Lawn and Garden Equipment Use Survey
English
Did you use one or more Trimmers/Edgers/Brush Cutters during 2022?
Yes
No
How many Trimmers/Edgers/Brush Cutters of the following types did you use at your residence last year?
Note: 2-stroke engines require gasoline mixed with 2-stroke oil.
Gasoline (2-Stroke)
Gasoline (4-Stroke)
Electric

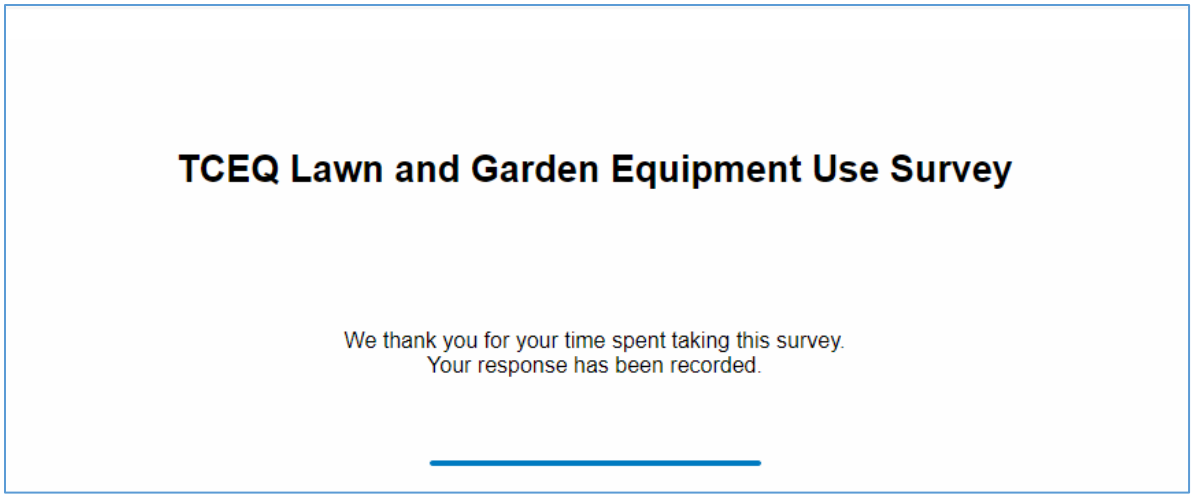

Restart Survey
Place Bookmark
Tools
TCEQ Lawn and Garden Equipment Use Survey
English
Did you use one or more Rear Engine Riding Mowers during 2022?
Yes
No
How many Rear Engine Riding Mowers of the following types did you use at your residence last year?
Gasoline (4-Stroke)
Electric


Restart Survey
Place Bookmark
Tools
TCEQ Lawn and Garden Equipment Use Survey
English
Did you use one or more Chain Saws (less than 6 horsepower) during 2022?
Yes
No
How many Chain Saws (less than 6 horsepower) of the following types did you use at your residence last year?
Note: 2-stroke engines require gasoline mixed with 2-stroke oil.
Gasoline (2-Stroke)
Gasoline (4-Stroke)
Electric


Restart Survey
Place Bookmark
Tools
TCEQ Lawn and Garden Equipment Use Survey
English
Did you use one or more Lawn & Garden Tractors during 2022?
Yes
No
How many Lawn & Garden Tractors of the following types did you use at your residence last year?
Gasoline (4-Stroke)
Electric


Restart Survey
Place Bookmark
Tools
TCEQ Lawn and Garden Equipment Use Survey
English
Did you use one or more Rotary Tillers (less than 6 horsepower) during 2022?
Yes
No
How many Rotary Tillers (less than 6 horsepower) of the following types did you use at your residence last year?
Note: 2-stroke engines require gasoline mixed with 2-stroke oil.
Gasoline (2-Stroke)
Gasoline (4-Stroke)
Electric


Restart Survey
Place Bookmark
Tools
TCEQ Lawn and Garden Equipment Use Survey
English
Thank you for the information. Just one more question for you.
What county do you currently reside in?
←
SUBMIT


TCEQ Lawn and Garden Equipment Use Survey
We thank you for your time spent taking this survey.
Your response has been recorded.

Appendix B – L&G Survey Respondents by County (N=780)

County	Responses
Anderson County, TX	8
Angelina County, TX	8
Aransas County, TX	1
Atascosa County, TX	2
Austin County, TX	8
Bandera County, TX	3
Bastrop County, TX	12
Baylor County, TX	1
Bee County, TX	3
Bell County, TX	7
Bexar County, TX	24
Blanco County, TX	1
Bosque County, TX	2
Brazoria County, TX	4
Brazos County, TX	7
Brewster County, TX	1
Burleson County, TX	4
Burnet County, TX	14
Caldwell County, TX	9
Cameron County, TX	2
Camp County, TX	1
Cass County, TX	4
Chambers County, TX	3
Cherokee County, TX	4
Coke County, TX	1
Collin County, TX	21
Colorado County, TX	2
Comal County, TX	6
Comanche County, TX	3
Concho County, TX	2
Cooke County, TX	3
Coryell County, TX	1
Crosby County, TX	1
Dallas County, TX	35
Denton County, TX	15
DeWitt County, TX	2
Donley County, TX	1
Eastland County, TX	4

County	Responses
Ector County, TX	3
El Paso County, TX	9
Ellis County, TX	3
Erath County, TX	5
Falls County, TX	1
Fayette County, TX	10
Fisher County, TX	2
Foard County, TX	1
Fort Bend County, TX	10
Franklin County, TX	1
Freestone County, TX	1
Frio County, TX	2
Galveston County, TX	10
Gillespie County, TX	6
Goliad County, TX	2
Gonzales County, TX	2
Grayson County, TX	3
Gregg County, TX	2
Grimes County, TX	6
Guadalupe County, TX	4
Hale County, TX	1
Hamilton County, TX	2
Hardeman County, TX	1
Hardin County, TX	5
Harris County, TX	47
Harrison County, TX	4
Haskell County, TX	1
Hays County, TX	5
Henderson County, TX	13
Hidalgo County, TX	6
Hill County, TX	10
Hood County, TX	1
Hopkins County, TX	7
Houston County, TX	1
Hunt County, TX	13
Jackson County, TX	2
Jasper County, TX	4
Jefferson County, TX	3

County	Responses
Jim Wells County, TX	3
Johnson County, TX	3
Jones County, TX	1
Karnes County, TX	1
Kaufman County, TX	3
Kendall County, TX	10
Kerr County, TX	3
Lamar County, TX	1
Lamb County, TX	1
Lampasas County, TX	6
Lavaca County, TX	4
Lee County, TX	2
Leon County, TX	3
Liberty County, TX	6
Limestone County, TX	2
Live Oak County, TX	1
Llano County, TX	7
Lubbock County, TX	9
Madison County, TX	4
Marion County, TX	3
Maverick County, TX	2
Medina County, TX	8
Midland County, TX	5
Mills County, TX	1
Montague County, TX	4
Montgomery County, TX	9
Morris County, TX	1
Nacogdoches County, TX	3
Navarro County, TX	2
Newton County, TX	1
Nueces County, TX	7
Palo Pinto County, TX	3
Panola County, TX	2
Parker County, TX	21
Polk County, TX	7

County	Responses
Potter County, TX	1
Rains County, TX	2
Randall County, TX	5
Red River County, TX	1
Rockwall County, TX	7
Runnels County, TX	2
Rusk County, TX	8
Sabine County, TX	1
San Saba County, TX	1
Shackelford County, TX	1
Shelby County, TX	1
Smith County, TX	6
Stonewall County, TX	1
Swisher County, TX	1
Tarrant County, TX	27
Taylor County, TX	2
Titus County, TX	1
Tom Green County, TX	2
Travis County, TX	33
Tyler County, TX	7
Upshur County, TX	5
Val Verde County, TX	2
Van Zandt County, TX	11
Walker County, TX	2
Waller County, TX	3
Washington County, TX	3
Webb County, TX	1
Wheeler County, TX	2
Wichita County, TX	4
Williamson County, TX	17
Wilson County, TX	6
Wise County, TX	11
Wood County, TX	13
Young County, TX	2

Appendix C – Number of Single-family Homes per County by Survey Stratum (CDS data set, January 2023)

Urban Counties

Andrews	5,616
Angelina	30,286
Aransas	10,077
Bailey	2,279
Bee	7,770
Bell	109,311
Bexar	560,697
Bowie	31,988
Brazoria	114,576
Brazos	60,082
Brewster	2,982
Brooks	2,265
Brown	13,474
Caldwell	14,339
Calhoun	6,137
Cameron	102,907
Castro	1,688
Chambers	15,063
Childress	2,119
Collin	311,604
Comal	64,142
Coryell	20,555
Crane	1,501
Crockett	50
Dallam	2,281
Dallas	591,435
Dawson	4,118
Deaf Smith	5,688
Denton	270,734
DeWitt	6,851
Dimmit	2,324
Ector	50,517
Ellis	65,822
El Paso	231,493
Erath	14,503
Fort Bend	257,767

Frio	3,860
Galveston	110,886
Garza	1,589
Gray	7,697
Grayson	48,909
Gregg	38,536
Guadalupe	62,179
Hale	8,916
Hansford	1,317
Harris	1,132,353
Haskell	2,146
Hays	72,964
Hemphill	1,405
Hidalgo	206,692
Hockley	6,538
Hood	27,065
Howard	10,248
Hutchinson	7,268
Jefferson	78,346
Jim Hogg	1,728
Jim Wells	11,284
Johnson	61,285
Karnes	4,087
Kaufman	56,506
Kerr	18,840
Kimble	1,603
Kinney	4
Kleberg	8,684
Lamar	18,748
La Salle	1,521
Llano	10,381
Lubbock	92,720
Mcculloch	2,946
Mclennan	80,698
Matagorda	10,410
Maverick	14,009

Midland	51,031
Mitchell	2,643
Montgomery	217,940
Moore	5,029
Nacogdoches	20,798
Nolan	4,914
Nueces	101,303
Ochiltree	3,295
Orange	30,074
Pecos	3,745
Potter	34,927
Presidio	55
Randall	48,490
Reagan	1,134
Reeves	3,807
Rockwall	40,670
Runnels	3,900
San Patricio	20,969
San Saba	2,163
Scurry	5,645
Smith	78,877
Starr	16,034
Stephens	3,347
Sutton	1,077
Swisher	2,030
Tarrant	584,025
Taylor	47,456
Terry	3,946
Tom Green	38,590
Travis	300,186
Uvalde	6,826
Val Verde	14,396
Victoria	27,515
Walker	17,280
Ward	3,553
Webb	64,476
Wharton	13,355
Wichita	41,393
Wilbarger	4,972
Willacy	3,848
Williamson	197,125
Winkler	2,451
Yoakum	2,012
Young	7,009
Zapata	4,727
Zavala	2,487

Rural Counties

Anderson	16,419
Archer	1,839
Armstrong	330
Atascosa	14,302
Austin	11,161
Bandera	7,655
Bastrop	31,120
Baylor	1,482
Blanco	4,537
Borden	143
Bosque	6,932
Briscoe	310
Burleson	6,538
Burnet	19,730
Callahan	5,560
Camp	4,864
Carson	528
Cass	11,302
Cherokee	17,933
Clay	4,055
Cochran	803
Coke	738
Coleman	3,377
Collingsworth	1,128
Colorado	7,889
Comanche	5,555
Concho	443
Cooke	15,111
Cottle	137
Crosby	1,534
Culberson	98
Delta	2,000
Dickens	675
Donley	608
Duval	1,473
Eastland	6,499
Edwards	199
Falls	5,619
Fannin	12,534
Fayette	10,255

Fisher	1,496
Floyd	1,670
Foard	161
Franklin	4,910
Freestone	7,489
Gaines	5,295
Gillespie	11,013
Glasscock	224
Goliad	2,275
Gonzales	6,386
Grimes	10,941
Hall	1,127
Hamilton	3,413
Hardeman	1,277
Hardin	19,161
Harrison	24,120
Hartley	1,213
Henderson	34,811
Hill	13,642
Hopkins	13,359
Houston	7,862
Hudspeth	324
Hunt	35,894
Irion	166
Jack	2,819
Jackson	4,221
Jasper	12,670
Jeff Davis	383
Jones	5,980
Kendall	15,589
Kent	192
King	16
Knox	944
Lamb	3,066
Lampasas	8,207
Lavaca	7,826
Lee	6,130
Leon	5,308
Liberty	32,622
Limestone	7,775

Lipscomb	272
Live Oak	3,226
Lynn	1,375
McMullen	92
Madison	4,428
Marion	4,667
Martin	517
Mason	494
Medina	16,413
Menard	307
Milam	9,514
Mills	1,551
Montague	8,199
Morris	4,303
Motley	131
Navarro	17,477
Newton	4,744
Oldham	44
Palo Pinto	11,120
Panola	9,171
Parker	57,409
Parmer	1,975
Polk	17,532
Rains	4,818
Real	291
Red River	5,122
Refugio	1,528
Roberts	198
Robertson	5,922
Rusk	18,211
Sabine	5,055
San Augustine	3,821
San Jacinto	11,777
Schleicher	448
Shackelford	844
Shelby	9,474
Sherman	117
Somervell	2,442
Sterling	16
Stonewall	304
Terrell	26
Throckmorton	359
Titus	10,039
Trinity	5,659
Tyler	7,001
Upshur	15,567
Upton	98
Van Zandt	21,753
Waller	18,899
Washington	13,201
Wheeler	1,397
Wilson	16,605
Wise	25,244
Wood	18,989

Appendix D – Estimated Number of Equipment Pieces by County (2022)

Urban Counties

County	4-strk Walk Behind Mowers	2-strk Blowers	4-strk Blowers	2-strk Trimmers	4-strk Trimmers	4-strk Riding Lawn Mowers	2-strk Chainsaws < 6 hp	4-strk Chainsaws < 6 hp	4-strk L&G Tractors	2-strk Tillers < 6 hp	4-strk Tillers < 6 hp
Andrews	3,075	1,144	74	1,530	163	579	1,189	74	535	178	119
Angelina	16,585	6,169	401	8,253	881	3,125	6,410	401	2,884	961	641
Aransas	5,518	2,053	133	2,746	293	1,040	2,133	133	960	320	213
Bailey	1,248	464	30	621	66	235	482	30	217	72	48
Bee	4,255	1,583	103	2,117	226	802	1,644	103	740	247	164
Bell	59,861	22,267	1,446	29,786	3,181	11,278	23,135	1,446	10,411	3,470	2,313
Bexar	307,048	114,216	7,417	152,783	16,317	57,850	118,666	7,417	53,400	17,800	11,867
Bowie	17,517	6,516	423	8,716	931	3,300	6,770	423	3,046	1,015	677
Brazoria	62,744	23,340	1,516	31,220	3,334	11,821	24,249	1,516	10,912	3,637	2,425
Brazos	32,902	12,239	795	16,372	1,748	6,199	12,716	795	5,722	1,907	1,272
Brewster	1,633	607	39	813	87	308	631	39	284	95	63
Brooks	1,240	461	30	617	66	234	479	30	216	72	48
Brown	7,379	2,745	178	3,671	392	1,390	2,852	178	1,283	428	285
Caldwell	7,852	2,921	190	3,907	417	1,479	3,035	190	1,366	455	303
Calhoun	3,361	1,250	81	1,672	179	633	1,299	81	584	195	130
Cameron	56,354	20,963	1,361	28,041	2,995	10,617	21,779	1,361	9,801	3,267	2,178
Castro	924	344	22	460	49	174	357	22	161	54	36
Chambers	8,249	3,068	199	4,104	438	1,554	3,188	199	1,435	478	319
Childress	1,160	432	28	577	62	219	448	28	202	67	45
Collin	170,640	63,475	4,122	84,908	9,068	32,150	65,948	4,122	29,677	9,892	6,595
Comal	35,125	13,066	848	17,478	1,867	6,618	13,575	848	6,109	2,036	1,358
Coryell	11,256	4,187	272	5,601	598	2,121	4,350	272	1,958	653	435
Crane	822	306	20	409	44	155	318	20	143	48	32

County	4-strk Walk Behind Mowers	2-strk Blowers	4-strk Blowers	2-strk Trimmers	4-strk Trimmers	4-strk Riding Lawn Mowers	2-strk Chainsaws < 6 hp	4-strk Chainsaws < 6 hp	4-strk L&G Tractors	2-strk Tillers < 6 hp	4-strk Tillers < 6 hp
Crockett	27	10	1	14	1	5	11	1	5	2	1
Dallam	1,249	465	30	622	66	235	483	30	217	72	48
Dallas	323,881	120,478	7,823	161,158	17,211	61,021	125,171	7,823	56,327	18,776	12,517
Dawson	2,255	839	54	1,122	120	425	872	54	392	131	87
Deaf Smith	3,115	1,159	75	1,550	166	587	1,204	75	542	181	120
Denton	148,259	55,150	3,581	73,771	7,879	27,933	57,298	3,581	25,784	8,595	5,730
DeWitt	3,752	1,396	91	1,867	199	707	1,450	91	652	217	145
Dimmit	1,273	473	31	633	68	240	492	31	221	74	49
Ector	27,664	10,291	668	13,765	1,470	5,212	10,691	668	4,811	1,604	1,069
Ellis	36,045	13,408	871	17,936	1,915	6,791	13,931	871	6,269	2,090	1,393
El Paso	126,770	47,156	3,062	63,079	6,737	23,884	48,993	3,062	22,047	7,349	4,899
Erath	7,942	2,954	192	3,952	422	1,496	3,069	192	1,381	460	307
Fort Bend	141,158	52,508	3,410	70,238	7,501	26,595	54,554	3,410	24,549	8,183	5,455
Frio	2,114	786	51	1,052	112	398	817	51	368	123	82
Galveston	60,723	22,588	1,467	30,215	3,227	11,441	23,468	1,467	10,561	3,520	2,347
Garza	870	324	21	433	46	164	336	21	151	50	34
Gray	4,215	1,568	102	2,097	224	794	1,629	102	733	244	163
Grayson	26,784	9,963	647	13,327	1,423	5,046	10,351	647	4,658	1,553	1,035
Gregg	21,103	7,850	510	10,501	1,121	3,976	8,156	510	3,670	1,223	816
Guadalupe	34,050	12,666	822	16,943	1,809	6,415	13,160	822	5,922	1,974	1,316
Hale	4,883	1,816	118	2,429	259	920	1,887	118	849	283	189
Hansford	721	268	17	359	38	136	279	17	125	42	28
Harris	620,098	230,665	14,978	308,551	32,952	116,830	239,651	14,978	107,843	35,948	23,965
Haskell	1,175	437	28	585	62	221	454	28	204	68	45
Hays	39,956	14,863	965	19,882	2,123	7,528	15,442	965	6,949	2,316	1,544
Hemphill	769	286	19	383	41	145	297	19	134	45	30
Hidalgo	113,188	42,104	2,734	56,321	6,015	21,325	43,744	2,734	19,685	6,562	4,374

County	4-strk Walk Behind Mowers	2-strk Blowers	4-strk Blowers	2-strk Trimmers	4-strk Trimmers	4-strk Riding Lawn Mowers	2-strk Chainsaws < 6 hp	4-strk Chainsaws < 6 hp	4-strk L&G Tractors	2-strk Tillers < 6 hp	4-strk Tillers < 6 hp
Hockley	3,580	1,332	86	1,782	190	675	1,384	86	623	208	138
Hood	14,821	5,513	358	7,375	788	2,792	5,728	358	2,578	859	573
Howard	5,612	2,088	136	2,792	298	1,057	2,169	136	976	325	217
Hutchinson	3,980	1,481	96	1,980	212	750	1,538	96	692	231	154
Jefferson	42,904	15,959	1,036	21,348	2,280	8,083	16,581	1,036	7,462	2,487	1,658
Jim Hogg	946	352	23	471	50	178	366	23	165	55	37
Jim Wells	6,179	2,299	149	3,075	328	1,164	2,388	149	1,075	358	239
Johnson	33,561	12,484	811	16,699	1,783	6,323	12,970	811	5,837	1,946	1,297
Karnes	2,238	833	54	1,114	119	422	865	54	389	130	86
Kaufman	30,944	11,510	747	15,397	1,644	5,830	11,959	747	5,382	1,794	1,196
Kerr	10,317	3,838	249	5,134	548	1,944	3,987	249	1,794	598	399
Kimble	878	327	21	437	47	165	339	21	153	51	34
Kinney	2	1	0	1	0	0	1	0	0	0	0
Kleberg	4,756	1,769	115	2,366	253	896	1,838	115	827	276	184
Lamar	10,267	3,819	248	5,109	546	1,934	3,968	248	1,786	595	397
La Salle	833	310	20	414	44	157	322	20	145	48	32
Llano	5,685	2,115	137	2,829	302	1,071	2,197	137	989	330	220
Lubbock	50,775	18,887	1,226	25,265	2,698	9,566	19,623	1,226	8,830	2,943	1,962
Mcculloch	1,613	600	39	803	86	304	623	39	281	94	62
Mclennan	44,192	16,438	1,067	21,989	2,348	8,326	17,079	1,067	7,686	2,562	1,708
Matagorda	5,701	2,121	138	2,837	303	1,074	2,203	138	991	330	220
Maverick	7,672	2,854	185	3,817	408	1,445	2,965	185	1,334	445	296
Midland	27,946	10,395	675	13,905	1,485	5,265	10,800	675	4,860	1,620	1,080
Mitchell	1,447	538	35	720	77	273	559	35	252	84	56
Montgomery	119,348	44,395	2,883	59,386	6,342	22,486	46,125	2,883	20,756	6,919	4,612
Moore	2,754	1,024	67	1,370	146	519	1,064	67	479	160	106
Nacogdoches	11,389	4,237	275	5,667	605	2,146	4,402	275	1,981	660	440

County	4-strk Walk Behind Mowers	2-strk Blowers	4-strk Blowers	2-strk Trimmers	4-strk Trimmers	4-strk Riding Lawn Mowers	2-strk Chainsaws < 6 hp	4-strk Chainsaws < 6 hp	4-strk L&G Tractors	2-strk Tillers < 6 hp	4-strk Tillers < 6 hp
Nolan	2,691	1,001	65	1,339	143	507	1,040	65	468	156	104
Nueces	55,475	20,636	1,340	27,604	2,948	10,452	21,440	1,340	9,648	3,216	2,144
Ochiltree	1,804	671	44	898	96	340	697	44	314	105	70
Orange	16,469	6,126	398	8,195	875	3,103	6,365	398	2,864	955	636
Pecos	2,051	763	50	1,020	109	386	793	50	357	119	79
Potter	19,127	7,115	462	9,517	1,016	3,604	7,392	462	3,326	1,109	739
Presidio	30	11	1	15	2	6	12	1	5	2	1
Randall	26,554	9,878	641	13,213	1,411	5,003	10,262	641	4,618	1,539	1,026
Reagan	621	231	15	309	33	117	240	15	108	36	24
Reeves	2,085	776	50	1,037	111	393	806	50	363	121	81
Rockwall	22,272	8,285	538	11,082	1,184	4,196	8,607	538	3,873	1,291	861
Runnels	2,136	794	52	1,063	113	402	825	52	371	124	83
San Patricio	11,483	4,271	277	5,714	610	2,163	4,438	277	1,997	666	444
San Saba	1,185	441	29	589	63	223	458	29	206	69	46
Scurry	3,091	1,150	75	1,538	164	582	1,195	75	538	179	119
Smith	43,195	16,068	1,043	21,493	2,295	8,138	16,694	1,043	7,512	2,504	1,669
Starr	8,781	3,266	212	4,369	467	1,654	3,393	212	1,527	509	339
Stephens	1,833	682	44	912	97	345	708	44	319	106	71
Sutton	590	219	14	293	31	111	228	14	103	34	23
Swisher	1,112	414	27	553	59	209	430	27	193	64	43
Tarrant	319,823	118,968	7,725	159,139	16,995	60,257	123,603	7,725	55,621	18,540	12,360
Taylor	25,988	9,667	628	12,931	1,381	4,896	10,044	628	4,520	1,507	1,004
Terry	2,161	804	52	1,075	115	407	835	52	376	125	84
Tom Green	21,133	7,861	510	10,515	1,123	3,982	8,167	510	3,675	1,225	817
Travis	164,388	61,149	3,971	81,797	8,736	30,972	63,531	3,971	28,589	9,530	6,353
Uvalde	3,738	1,390	90	1,860	199	704	1,445	90	650	217	144
Val Verde	7,884	2,933	190	3,923	419	1,485	3,047	190	1,371	457	305

County	4-strk Walk Behind Mowers	2-strk Blowers	4-strk Blowers	2-strk Trimmers	4-strk Trimmers	4-strk Riding Lawn Mowers	2-strk Chainsaws < 6 hp	4-strk Chainsaws < 6 hp	4-strk L&G Tractors	2-strk Tillers < 6 hp	4-strk Tillers < 6 hp
Victoria	15,068	5,605	364	7,497	801	2,839	5,823	364	2,620	873	582
Walker	9,463	3,520	229	4,709	503	1,783	3,657	229	1,646	549	366
Ward	1,946	724	47	968	103	367	752	47	338	113	75
Webb	35,308	13,134	853	17,569	1,876	6,652	13,646	853	6,141	2,047	1,365
Wharton	7,313	2,720	177	3,639	389	1,378	2,826	177	1,272	424	283
Wichita	22,668	8,432	548	11,279	1,205	4,271	8,760	548	3,942	1,314	876
Wilbarger	2,723	1,013	66	1,355	145	513	1,052	66	474	158	105
Willacy	2,107	784	51	1,049	112	397	814	51	366	122	81
Williamson	107,949	40,155	2,607	53,714	5,736	20,338	41,720	2,607	18,774	6,258	4,172
Winkler	1,342	499	32	668	71	253	519	32	233	78	52
Yoakum	1,102	410	27	548	59	208	426	27	192	64	43
Young	3,838	1,428	93	1,910	204	723	1,483	93	668	223	148
Zapata	2,589	963	63	1,288	138	488	1,000	63	450	150	100
Zavala	1,362	507	33	678	72	257	526	33	237	79	53
Total - Urban	**4,003,607**	**1,489,264**	**96,705**	**1,992,133**	**212,752**	**754,303**	**1,547,288**	**96,705**	**696,279**	**232,093**	**154,729**

Rural Counties

County	4-strk Walk Behind Mowers	2-strk Blowers	4-strk Blowers	2-strk Trimmers	4-strk Trimmers	4-strk Riding Lawn Mowers	2-strk Chainsaws < 6 hp	4-strk Chainsaws < 6 hp	4-strk L&G Tractors	2-strk Tillers < 6 hp	4-strk Tillers < 6 hp
Anderson	16,051	4,750	737	7,719	1,470	7,556	10,164	288	6,045	983	1,146
Archer	1,798	532	83	865	165	846	1,138	32	677	110	128
Armstrong	323	95	15	155	30	152	204	6	121	20	23
Atascosa	13,982	4,137	642	6,724	1,281	6,582	8,854	251	5,265	856	999
Austin	10,911	3,229	501	5,247	999	5,136	6,909	196	4,109	668	779
Bandera	7,484	2,214	344	3,599	686	3,523	4,739	134	2,818	458	535
Bastrop	30,423	9,002	1,397	14,631	2,787	14,321	19,265	546	11,457	1,863	2,173
Baylor	1,449	429	67	697	133	682	917	26	546	89	103
Blanco	4,435	1,312	204	2,133	406	2,088	2,809	80	1,670	272	317
Borden	140	41	6	67	13	66	89	3	53	9	10
Bosque	6,777	2,005	311	3,259	621	3,190	4,291	122	2,552	415	484
Briscoe	303	90	14	146	28	143	192	5	114	19	22
Burleson	6,392	1,891	293	3,074	585	3,009	4,047	115	2,407	391	457
Burnet	19,288	5,707	886	9,276	1,767	9,080	12,214	346	7,264	1,181	1,378
Callahan	5,436	1,608	250	2,614	498	2,559	3,442	98	2,047	333	388
Camp	4,755	1,407	218	2,287	436	2,238	3,011	85	1,791	291	340
Carson	516	153	24	248	47	243	327	9	194	32	37
Cass	11,049	3,269	507	5,314	1,012	5,201	6,996	198	4,161	676	789
Cherokee	17,532	5,188	805	8,431	1,606	8,253	11,101	315	6,602	1,073	1,252
Clay	3,964	1,173	182	1,906	363	1,866	2,510	71	1,493	243	283
Cochran	785	232	36	378	72	370	497	14	296	48	56
Coke	721	213	33	347	66	340	457	13	272	44	52
Coleman	3,301	977	152	1,588	302	1,554	2,091	59	1,243	202	236
Collingsworth	1,103	326	51	530	101	519	698	20	415	68	79

County	4-strk Walk Behind Mowers	2-strk Blowers	4-strk Blowers	2-strk Trimmers	4-strk Trimmers	4-strk Riding Lawn Mowers	2-strk Chainsaws < 6 hp	4-strk Chainsaws < 6 hp	4-strk L&G Tractors	2-strk Tillers < 6 hp	4-strk Tillers < 6 hp
Colorado	7,712	2,282	354	3,709	706	3,631	4,884	138	2,904	472	551
Comanche	5,431	1,607	249	2,612	497	2,556	3,439	97	2,045	332	388
Concho	433	128	20	208	40	204	274	8	163	27	31
Cooke	14,773	4,371	678	7,104	1,353	6,954	9,354	265	5,563	904	1,055
Cottle	134	40	6	64	12	63	85	2	50	8	10
Crosby	1,500	444	69	721	137	706	950	27	565	92	107
Culberson	96	28	4	46	9	45	61	2	36	6	7
Delta	1,955	579	90	940	179	920	1,238	35	736	120	140
Dickens	660	195	30	317	60	311	418	12	249	40	47
Donley	594	176	27	286	54	280	376	11	224	36	42
Duval	1,440	426	66	693	132	678	912	26	542	88	103
Eastland	6,354	1,880	292	3,056	582	2,991	4,023	114	2,393	389	454
Edwards	195	58	9	94	18	92	123	3	73	12	14
Falls	5,493	1,625	252	2,642	503	2,586	3,478	99	2,069	336	392
Fannin	12,253	3,626	563	5,893	1,122	5,768	7,759	220	4,615	750	875
Fayette	10,025	2,967	460	4,821	918	4,719	6,348	180	3,775	614	716
Fisher	1,463	433	67	703	134	688	926	26	551	90	104
Floyd	1,633	483	75	785	150	769	1,034	29	615	100	117
Foard	157	47	7	76	14	74	100	3	59	10	11
Franklin	4,800	1,420	220	2,308	440	2,260	3,040	86	1,808	294	343
Freestone	7,321	2,166	336	3,521	671	3,446	4,636	131	2,757	448	523
Gaines	5,176	1,532	238	2,489	474	2,437	3,278	93	1,949	317	370
Gillespie	10,766	3,186	494	5,178	986	5,068	6,818	193	4,055	659	769
Glasscock	219	65	10	105	20	103	139	4	82	13	16
Goliad	2,224	658	102	1,070	204	1,047	1,408	40	838	136	159

County	4-strk Walk Behind Mowers	2-strk Blowers	4-strk Blowers	2-strk Trimmers	4-strk Trimmers	4-strk Riding Lawn Mowers	2-strk Chainsaws < 6 hp	4-strk Chainsaws < 6 hp	4-strk L&G Tractors	2-strk Tillers < 6 hp	4-strk Tillers < 6 hp
Gonzales	6,243	1,847	287	3,002	572	2,939	3,953	112	2,351	382	446
Grimes	10,696	3,165	491	5,144	980	5,035	6,773	192	4,028	655	764
Hall	1,102	326	51	530	101	519	698	20	415	67	79
Hamilton	3,337	987	153	1,605	306	1,571	2,113	60	1,257	204	238
Hardeman	1,248	369	57	600	114	588	791	22	470	76	89
Hardin	18,732	5,543	860	9,009	1,716	8,818	11,862	336	7,054	1,147	1,338
Harrison	23,580	6,977	1,083	11,340	2,160	11,100	14,931	423	8,880	1,444	1,684
Hartley	1,186	351	54	570	109	558	751	21	447	73	85
Henderson	34,032	10,070	1,563	16,366	3,117	16,020	21,550	611	12,816	2,083	2,431
Hill	13,337	3,946	612	6,414	1,222	6,278	8,445	239	5,022	816	953
Hopkins	13,060	3,864	600	6,281	1,196	6,148	8,270	234	4,918	800	933
Houston	7,686	2,274	353	3,696	704	3,618	4,867	138	2,894	471	549
Hudspeth	317	94	15	152	29	149	201	6	119	19	23
Hunt	35,090	10,383	1,611	16,876	3,214	16,518	22,220	630	13,215	2,148	2,506
Irion	162	48	7	78	15	76	103	3	61	10	12
Jack	2,756	815	127	1,325	252	1,297	1,745	49	1,038	169	197
Jackson	4,127	1,221	189	1,985	378	1,943	2,613	74	1,554	253	295
Jasper	12,386	3,665	569	5,957	1,135	5,831	7,843	222	4,665	758	885
Jeff Davis	374	111	17	180	34	176	237	7	141	23	27
Jones	5,846	1,730	268	2,811	536	2,752	3,702	105	2,202	358	418
Kendall	15,240	4,510	700	7,329	1,396	7,174	9,650	273	5,739	933	1,089
Kent	188	56	9	90	17	88	119	3	71	11	13
King	16	5	1	8	1	7	10	0	6	1	1
Knox	923	273	42	444	85	434	584	17	348	56	66
Lamb	2,997	887	138	1,441	275	1,411	1,898	54	1,129	184	214

County	4-strk Walk Behind Mowers	2-strk Blowers	4-strk Blowers	2-strk Trimmers	4-strk Trimmers	4-strk Riding Lawn Mowers	2-strk Chainsaws < 6 hp	4-strk Chainsaws < 6 hp	4-strk L&G Tractors	2-strk Tillers < 6 hp	4-strk Tillers < 6 hp
Lampasas	8,023	2,374	368	3,859	735	3,777	5,081	144	3,021	491	573
Lavaca	7,651	2,264	351	3,679	701	3,602	4,845	137	2,881	468	546
Lee	5,993	1,773	275	2,882	549	2,821	3,795	108	2,257	367	428
Leon	5,189	1,535	238	2,496	475	2,443	3,286	93	1,954	318	371
Liberty	31,892	9,437	1,464	15,337	2,921	15,013	20,195	572	12,010	1,952	2,278
Limestone	7,601	2,249	349	3,655	696	3,578	4,813	136	2,862	465	543
Lipscomb	266	79	12	128	24	125	168	5	100	16	19
Live Oak	3,154	933	145	1,517	289	1,485	1,997	57	1,188	193	225
Lynn	1,344	398	62	646	123	633	851	24	506	82	96
McMullen	90	27	4	43	8	42	57	2	34	6	6
Madison	4,329	1,281	199	2,082	397	2,038	2,741	78	1,630	265	309
Marion	4,563	1,350	209	2,194	418	2,148	2,889	82	1,718	279	326
Martin	505	150	23	243	46	238	320	9	190	31	36
Mason	483	143	22	232	44	227	306	9	182	30	34
Medina	16,046	4,748	737	7,717	1,470	7,553	10,160	288	6,043	982	1,146
Menard	300	89	14	144	27	141	190	5	113	18	21
Milam	9,301	2,752	427	4,473	852	4,378	5,890	167	3,503	569	664
Mills	1,516	449	70	729	139	714	960	27	571	93	108
Montague	8,015	2,372	368	3,855	734	3,773	5,076	144	3,019	491	572
Morris	4,207	1,245	193	2,023	385	1,980	2,664	75	1,584	258	300
Motley	128	38	6	62	12	60	81	2	48	8	9
Navarro	17,086	5,056	785	8,217	1,565	8,043	10,819	307	6,434	1,046	1,220
Newton	4,638	1,372	213	2,230	425	2,183	2,937	83	1,747	284	331
Oldham	43	13	2	21	4	20	27	1	16	3	3
Palo Pinto	10,871	3,217	499	5,228	996	5,117	6,884	195	4,094	666	776

County	4-strk Walk Behind Mowers	2-strk Blowers	4-strk Blowers	2-strk Trimmers	4-strk Trimmers	4-strk Riding Lawn Mowers	2-strk Chainsaws < 6 hp	4-strk Chainsaws < 6 hp	4-strk L&G Tractors	2-strk Tillers < 6 hp	4-strk Tillers < 6 hp
Panola	8,966	2,653	412	4,312	821	4,220	5,677	161	3,376	549	640
Parker	56,124	16,607	2,577	26,991	5,141	26,420	35,539	1,007	21,136	3,436	4,009
Parmer	1,931	571	89	929	177	909	1,223	35	727	118	138
Polk	17,139	5,072	787	8,243	1,570	8,068	10,853	308	6,455	1,049	1,224
Rains	4,710	1,394	216	2,265	431	2,217	2,983	85	1,774	288	336
Real	284	84	13	137	26	134	180	5	107	17	20
Red River	5,007	1,482	230	2,408	459	2,357	3,171	90	1,886	307	358
Refugio	1,494	442	69	718	137	703	946	27	563	91	107
Roberts	194	57	9	93	18	91	123	3	73	12	14
Robertson	5,789	1,713	266	2,784	530	2,725	3,666	104	2,180	354	414
Rusk	17,803	5,268	817	8,562	1,631	8,381	11,273	319	6,705	1,090	1,272
Sabine	4,942	1,462	227	2,377	453	2,326	3,129	89	1,861	303	353
San Augustine	3,735	1,105	172	1,796	342	1,758	2,365	67	1,407	229	267
San Jacinto	11,513	3,407	529	5,537	1,055	5,420	7,291	207	4,336	705	822
Schleicher	438	130	20	211	40	206	277	8	165	27	31
Shackelford	825	244	38	397	76	388	522	15	311	51	59
Shelby	9,262	2,741	425	4,454	848	4,360	5,865	166	3,488	567	662
Sherman	114	34	5	55	10	54	72	2	43	7	8
Somervell	2,387	706	110	1,148	219	1,124	1,512	43	899	146	171
Sterling	16	5	1	8	1	7	10	0	6	1	1
Stonewall	297	88	14	143	27	140	188	5	112	18	21
Terrell	25	8	1	12	2	12	16	0	10	2	2
Throckmorton	351	104	16	169	32	165	222	6	132	21	25
Titus	9,814	2,904	451	4,720	899	4,620	6,215	176	3,696	601	701
Trinity	5,532	1,637	254	2,661	507	2,604	3,503	99	2,083	339	395

County	4-strk Walk Behind Mowers	2-strk Blowers	4-strk Blowers	2-strk Trimmers	4-strk Trimmers	4-strk Riding Lawn Mowers	2-strk Chainsaws < 6 hp	4-strk Chainsaws < 6 hp	4-strk L&G Tractors	2-strk Tillers < 6 hp	4-strk Tillers < 6 hp
Tyler	6,844	2,025	314	3,292	627	3,222	4,334	123	2,577	419	489
Upshur	15,218	4,503	699	7,319	1,394	7,164	9,637	273	5,731	932	1,087
Upton	96	28	4	46	9	45	61	2	36	6	7
Van Zandt	21,266	6,293	976	10,227	1,948	10,011	13,466	382	8,009	1,302	1,519
Waller	18,476	5,467	848	8,885	1,692	8,697	11,699	332	6,958	1,131	1,320
Washington	12,905	3,819	593	6,206	1,182	6,075	8,172	232	4,860	790	922
Wheeler	1,366	404	63	657	125	643	865	25	514	84	98
Wilson	16,233	4,803	745	7,807	1,487	7,642	10,279	291	6,113	994	1,159
Wise	24,679	7,303	1,133	11,868	2,261	11,617	15,627	443	9,294	1,511	1,763
Wood	18,564	5,493	852	8,928	1,701	8,739	11,755	333	6,991	1,136	1,326
Total - Rural	**943,961**	**279,319**	**43,343**	**453,966**	**86,470**	**444,358**	**597,739**	**16,940**	**355,486**	**57,790**	**67,422**

Appendix E – Quality Assurance Procedures and findings

ERG transformed data collected under the residential L&G equipment survey and the 50-state small SI engine certification assessment into new tables for emissions modeling. The new L&G equipment counts were translated into an updated 'PopulationYears' table in the TexN2 database. The new information on prevalence of side vs. overhead valves on small SI engines were translated into a new 'NREngTechFraction' table to be used by TexN2 when setting up inputs for MOVES runs that include any small SI engine equipment of model year 2012 and later (corresponding equipment meeting Phase 3 engine standards).

Residential L&G Equipment Emissions Modeling QA

ERG assembled the L&G equipment survey results and the single-family home count surrogates into an Excel spreadsheet that was independently reviewed by two additional ERG staff. The spreadsheet combined these two data sources and produced total, gasoline-only, and electric residential L&G equipment population counts by county. The equipment types covered by the survey correspond to the ten SCCs in Table E-1.

Table E-1. SCCs for the Residential L&G Equipment Covered by Survey

SCC	Description of Equipment
2260004015	2-Stroke Rotary Tillers < 6 HP (residential)
2265004015	4-Stroke Rotary Tillers < 6 HP (residential)
2260004020	2-Stroke Chainsaws < 6 HP (residential)
2260004025	2-Stroke Trimmers/Edgers/Brush Cutter (residential)
2265004025	4-Stroke Trimmers/Edgers/Brush Cutter (residential)
2260004030	2-Stroke Leafblowers/Vacuums (residential)
2265004030	4-Stroke Leafblowers/Vacuums (residential)
2265004010	4-Stroke Lawn mowers (residential)
2265004040	4-Stroke Rear Engine Riding Mowers (residential)
2265004055	4-Stroke Lawn & Garden Tractors (residential)

Equipment populations in the TexN2 database are listed in the `PopulationYears` table by a population ID code ranging from one (1) to over 1.4 million (1,414,780) and calendar year 1990 and 1999 to 2060. The population ID codes are defined in another TexN2 database table named `PopulationMain` as a combination of county, SCC, diesel construction equipment (DCE) subsector for diesel-fueled SCCs (which are not part of this update), and rated HP bin. The Excel spreadsheet listed populations by county and SCC, but not HP because it was not included in the survey. ERG adopted the default relative distributions to allocate new equipment populations to the existing HP categories for gasoline-fueled residential L&G equipment. Table E-2 shows the surveyed number of equipment, totals pieces and per household surveyed, separately for urban and rural counties. Table E-3 summarizes the survey breakout of 2-stroke vs. 4-stroke engines for the equipment types that have both.

Table E-2. Equipment Numbers and Average Equipment Numbers per Surveyed Household

	Urban Counties		Rural Counties	
Equipment	**# Pieces**	**Avg #/Household**	**# Pieces**	**Avg #/Household**
Walk Behind Mowers	271	0.72	431	1.07
Leafblowers/Vacuums	307	0.81	360	0.90
Trimmers/Edgers/Brush Cutter	305	0.81	386	0.96
Riding Mowers	40	0.11	190	0.47
Chainsaws < 6 HP	169	0.45	356	0.89
Lawn & Garden Tractors	36	0.10	151	0.38
Rotary Tillers < 6 HP	27	0.07	65	0.16
All Equipment	**1,155**	**3.06**	**1,939**	**4.82**

Table E-3. Two-Stroke vs. Four-Stroke Equipment for Leaf Blowers, Trimmers, Chainsaws, and Tillers

Equipment	2-Stroke	4-Stroke
Urban		
Leaf blowers	94%	6%
Trimmers	90%	10%
Chainsaws	100%	0%
Tillers	60%	40%
Rural		
Leaf blowers	87%	13%
Trimmers	84%	16%
Chainsaws	97%	3%
Tillers	46%	54%

ERG applied a script to read the raw data from the Excel spreadsheet into a MySQL database, assign SCCs and county FIPS codes, allocate populations to the HP bin level, and update the appropriate populations for calendar year 2022 by county, SCC, and HP bin in the `PopulationYears`table. By automating the data read-in and processing steps, ERG performed repetitive calculations quickly and consistently, eliminating the chances of human error. For each of the major steps involved, ERG compared the number of data rows expected to the number produced by the script as a result of the calculation. ERG also verified the population totals matched expectations after the reallocation to various categories by summing the new TexN2 tables directly for the ten SCCs and by running a statewide scenario.

ERG performed a TexN2 annual run for calendar year 2022 for three cases: (1) prior to the L&G equipment population update, (2) with updated residential L&G equipment totals that did not remove the electric portion of equipment (i.e., all gas and electric included under the gasoline SCC populations), and (3) gasoline-only (i.e., excluding electric equipment). Table E-4 shows that the population totals summed over county and HP bin from TexN2 outputs match those of the raw data Excel file at the state level. The minor differences in Table E-4 of one (1)

equipment count in the totals row, and for some SCCs, is a result of minor rounding differences and does not significantly impact the emissions inventory.

Table E-4. Matching Statewide Populations in the Raw Data vs. TexN2 Outputs for the 2022 Year

SCC	SCC description	TexN2 Outputs			Survey + Surrogate Raw Data	
		TexN2 Existing Population	Updated Population: Gasoline & Electric	Updated Population: Gasoline Only (No electric)	Raw Data: Gasoline & Electric	Raw Data: Gasoline Only (No electric)
2265004010	4-strk Walk Behind Mowers	3,668,429	6,276,671	4,947,568	6,276,671	4,947,567
2260004030	2-strk Leaf Blowers	783,658	6,326,071	1,768,585	6,326,070	1,768,584
2265004030	4-strk Leaf Blowers	40,738	478,498	140,048	478,499	140,048
2260004025	2-strk Trimmers	1,544,599	6,108,633	2,446,098	6,108,633	2,446,099
2265004025	4-strk Trimmers	25,253	717,549	299,222	717,549	299,222
2265004040	4-strk Riding Lawn Mowers	195,873	1,230,011	1,198,659	1,230,012	1,198,661
2260004020	2-strk Chainsaws < 6 HP	584,985	4,130,163	2,258,672	4,130,163	2,258,672
2265004055	4-strk L&G Tractors	1,338,543	1,058,972	1,051,766	1,058,972	1,051,766
2260004015	2-strk Tillers < 6 HP	51,945	385,563	289,883	385,563	289,883
2265004015	4-strk Tillers < 6 HP	323,173	293,162	222,150	293,161	222,151
Total		**8,557,196**	**27,005,294**	**14,622,651**	**27,005,293**	**14,622,652**

ERG performed QA on the modeled VOC and NO_x emissions estimates ensuring that emissions outputs from TexN2 tracked with population changes. Accounting for electric equipment relative to the new surveyed totals of all residential L&G equipment reduces the statewide population from 27 million to 14.6 million, or a 46 percent decrease. The corresponding statewide NO_x and VOC emissions reported in Deliverable 4.2 (LawnGarden_TexN2_Analysis_20230519.xlsx) decreased by only 24 percent and 41 percent, respectively. The emissions differences are directionally correct consistent with reduced population, but the magnitude is smaller because the larger HP equipment (e.g., Lawn and Garden Tractors) which also make up a larger proportion of the L&G residential sector emissions tend to be gasoline-fueled as opposed to operating on electricity.

50-State Certified Small SI Engines QA

ERG revised the `NREngTechFraction` table based on the contents and structure of the MOVES3 default table, updating the existing values of technology IDs 143 (overhead valve) and 144 (side-valve) for gasoline-fueled equipment less than 25 HP. First, ERG's script re-allocated the

technology ID fractions for 143 and 144 corresponding to model years between 2012 and 2017 to a relative split of 88% overhead valve and 12% side-valve. The EPA's default splits were 40% and 60%, respectively for these years. Next, ERG's script added a new model year, 2018, which MOVES will apply going forward so long as newer model years do not exist in the table. In the default table, the final model year ID was 2014, and the information gathered suggested that starting in 2018, 100% of sales are overhead valve. Therefore, the script assigned fractions of 0 to all technology IDs for model year 2018, except for technology ID 143 (overhead value) which was assigned a fraction of 1. ERG incorporated the script into the TexN2 utility, which should be revised if and when EPA releases an update to MOVES-Nonroad that modifies the `NREngTechFraction` table to ensure the reallocation to overhead valve technology continues to work as intended. This review should also be done to ensure that engine technologies turned on/off during the Automated RFP function in TexN2 are also continuing to work as intended.

ERG estimated the emissions impact of using the larger industry-reported overhead valve market shares in 2012 and later for a calendar year 2022 TexN2 run for all gasoline-fueled SCCs for Harris County and Bexar County in Deliverable 8.1 (SORE_TexN2_Analysis_20230523.xlsx). The VOC emissions benefit of modeling the updated overhead valve market share was 0.15 TPD and 0.33 TPD in Bexar and Harris, respectively, for a summer weekday ozone season day (OSD). The NO_x emissions change was actually a small disbenefit – an increase of 0.07 TPD and 0.16 TPD in Bexar and Harris for a summer weekday OSD in 2022. The NO_x increase was expected due to higher emission factors from overhead valve vs. side-valve technologies. Overhead valve better optimizes space and allows for an increased compression ratio, leading to higher efficiency and flame temperature, which is in turn associated with higher NO_x emissions but lower hydrocarbon emissions. The magnitude of the emissions change output by TexN2 generally agreed with the standalone MOVES3 analysis summarized in Tables 10 through 14 for the DFW 9-county NAR, for a July average day in 2023.