EMV Group A, Deliverable 16 EUL Research – Gas Fryers

Final Report

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Submitted by:

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Executive Summary

Introduction and Objective

This document outlines the effective useful life (EUL) research[1] conducted by Guidehouse on behalf of the California Public Utilities Commission (CPUC) for gas fryers. Gas fryers have a high degree of uncertainty[2] around technology savings and lifespan and have high first year and lifetime energy savings. As a result, Guidehouse prioritized gas fryers for this EUL research. In 2017, gas fryers accounted for 8% of first year and 9% lifetime savings of the gas portfolio (after removing home energy reports and codes and standards savings).[3]

EUL is defined as the median number of years since installation that the implemented equipment is still in place and operable.[4] The current, approved gas fryer EUL value is 12 years. Notably, 12 years is the EUL applied to *all* cooking appliance equipment and is not specific to gas fryers.[5]

The objective of this research was to review primary data and determine the EUL for gas fryers. The EUL findings of this report will inform the CPUC-approved EUL value for gas fryers incentivized through energy efficiency programs.

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[1] This research plan is part of the steps listed in the *Effective Useful Life (EUL) Study Work Plan* and accompanying *Measure Prioritization* document, https://pda.energydataweb.com/#!/documents/2191/view.

[2] Energy Division maps the thousands of measures in annual claims to 288 standardized measure groups for the purposes of aggregation and consistency across programs, PAs, and years. In a given program year, each measure associated with one or more claims is assigned a single measure group, allowing for application and comparison between evaluations of one year and claims of another. The Uncertain Measure List can be found here: http://www.cpuc.ca.gov/general.aspx?id=4137

[3] CEDARS, "Confirmed Claims Dashboards for 2017 (Cost Effectiveness Output)." California Energy Data and Reporting System, 2018. Online at https://cedars.sound-data.com. The prioritization is detailed in the following document: https://pda.energydataweb.com/api/downloads/2191/Measure%20Prioritization.pdf.

[4] California Public Utilities Commission, *California Energy Efficiency Evaluation Protocols: Technical, Methodological, and Reporting Requirements for Evaluation Professionals*, April 2006, http://www.cpuc.ca.gov/WorkArea/DownloadAsset.aspx?id=5212.

[5] California Public Utilities Commission, "2008 EUL/RUL Values DEER Update," http://deeresources.com/files/deer0911planning/downloads/EUL_Summary_10-1-08.xls.

Process

Guidehouse used data from a recent small commercial study, [6] which included a total of 36 onsite interviews and 175 telephone surveys of gas fryer participants. Guidehouse acquired the survey results and field site survey data and conducted an uncertainty analysis to fit the survey responses of the existing gas fryer's age. The following steps outline the methodology used to analyze the survey results to determine the updated EUL for gas fryers.

Step 1: Data cleaning – filter out non-applicable data from the 2017 evaluation site visit and phone survey data

The original survey asked respondents to choose from 5-year bins (0-5 years, 5-10, 10-15 years, 15+ years) to estimate the age of their existing fryer. Guidehouse screened out non-applicable responses and generated the most likely static-point estimate for the sample. Guidehouse combined the resultant estimates from the onsite surveys and the phone surveys to form a single dataset.[7]

Step 2: Curve fitting – use the compiled survey data to generate a best-fit distribution to determine the gas fryer survival curve[8]

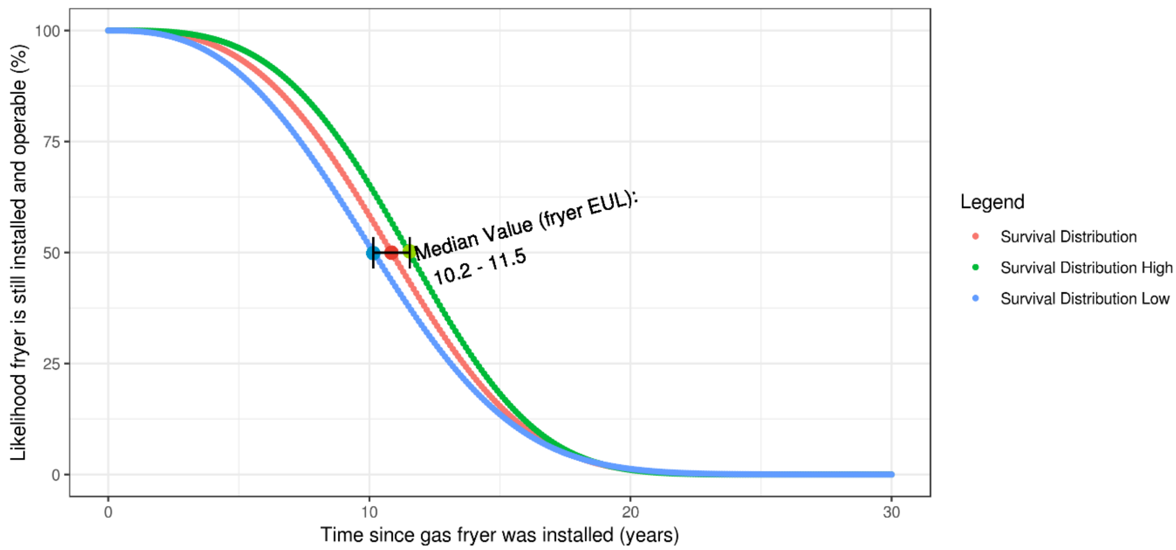
Guidehouse used statistical software to analyze (i.e., to generate a smooth curve that best approximates the sampled data) the age estimates of the existing fryer dataset to determine a best-fit distribution curve. Figure ES-1 shows the results with error bounds of the best-fit analysis using the raw small commercial study data, with the x-axis representing the time in years since a given gas fryer was installed and the y-axis representing the probability that fryer is still installed and operating. At time equals zero years, all fryers are still installed and operating. As time increases, the probability a fryer is still operating approaches zero. The central red point and corresponding error bars show the median value (i.e., the CPUC definition for determining EULs) from the distribution within one standard deviation.

[6] California Public Utility Commission, *2017 Small/Medium Commercial Sector ESPI Impact Evaluation,* April 2019. This report discusses the impact evaluation methodology and findings for several high impact Small/Medium Commercial PY 2017 electric and gas measures. For this analysis, Guidehouse only used the survey data related to commercial gas fryers. The impact evaluation report can be found here: https://pda.energydataweb.com/#!/documents/2162/view

[7] Guidehouse verified that the project IDs for the onsite survey dataset and telephone survey dataset were unique. There was one overlapping entry between the two datasets ("claim.id 1105462"). The duplicate telephone response was removed from the dataset during the data cleaning step.

[8] In product reliability literature, a survival curve is a function that represents the probability that a device is installed and operable as a function of time (this function ignores defective installs). At time zero, the probability is 100% that a product is installed and operable and as time increases, the probability decreases until it asymptotically approaches 0%.

Figure ES-1: Gas Fryer Cumulative EUL Distribution



Step 3: EUL estimation - determine the recommended gas fryer EUL

Guidehouse calculated the survival curve's median value (visually represented by the red dot along the red curve in Figure ES-1). After analysis and adjustment of all datapoints, the median expected value of the entire dataset is 11 years (10.2-11.5) for gas fryer EUL. This value is specific to gas fryers and not applicable to other cooking equipment.

Summary of Findings

Guidehouse used the small commercial study results to analytically determine the EUL for gas fryers. For this sample, more than 50 of the 88 total respondents stated that their existing gas fryer was between 5-10 years old when the new fryer was installed. This provides an initial indication that—using median age as the definition of EUL—the currently used gas fryer EUL value of 12 years may be too high. Using this data, Guidehouse then used statistical methods to generate a gas fryer survival curve resulting in a gas fryer EUL of 11 years (10.9 $\pm$ 0.6 years).

Recommendation

Guidehouse recommends that the CPUC consider the results of this study when determining the CPUC-approved EUL that will be used for gas fryers incentivized through energy efficiency funding.

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1. Introduction

1.1 Study Objectives

Guidehouse investigated recent California gas fryer installations and removals to determine an evidence-based value for gas fryer effective useful life (EUL). EUL is defined as the median number of years since installation that the implemented measures are still in place and operable.[9] The primary focus for this EUL research is to update the existing default EULs used in the statewide portfolio, including an update to the Database of Energy Efficiency Resources (DEER).[10]

Guidehouse prepared this study (EMV Group A, Deliverable 16 EUL Research, Gas Fryers) for the California Public Utilities Commission (CPUC). In June 2019, Guidehouse conducted a high impact measures analysis, ranking measures from two datasets. The first approach utilized the Uncertain Measure List,[11] which is at the measure category level, and the second approach utilized the measure level detail in the California Energy Data and Reporting System (CEDARS) extract for 2017.[12] Results from the prioritization process designated gas fryers as a high priority measure.[13]

The data source for this EUL analysis was the Itron 2017 Small/Medium Sector Commercial ESPI Impact Evaluation Report.[14] Guidehouse acquired and analyzed onsite interview data and telephone survey responses pertinent to gas fryers from the Itron study, including a total of 36 onsite interviews and 175 telephone surveys of gas fryer participants.

For this study, Guidehouse did not conduct any new data collection efforts and instead leveraged existing efforts. There are significant cost and effort savings associated with using historic and ongoing impact evaluation data via survey results. Additionally, the EUL modeling

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[9] California Public Utilities Commission, *California Energy Efficiency Evaluation Protocols: Technical, Methodological, and Reporting Requirements for Evaluation Professionals*, April 2006, http://www.cpuc.ca.gov/WorkArea/DownloadAsset.aspx?id=5212.

[10] DEER contains estimates of the energy savings potential of select energy efficient technologies and measures in residential and non-residential applications. The database also contains information on the costs and benefits of energy efficient measures.

[11] Energy Division maps the thousands of measures in annual claims to 288 standardized measure groups for the purposes of aggregation and consistency across programs, PAs, and years. In a given program year, each measure associated with one or more claims is assigned a single measure group, allowing for application and comparison between evaluations of one year and claims of another. The Uncertain Measure List can be found here: http://www.cpuc.ca.gov/general.aspx?id=4137

[12] CEDARS, "Confirmed Claims Dashboards for 2017 (Cost Effectiveness Output)," California Energy Data and Reporting System, 2018. Online at https://cedars.sound-data.com.

[13] Measure prioritization for EUL research, https://pda.energydataweb.com/api/downloads/2191/Measure%20Prioritization.pdf.

[14] California Public Utility Commission, *2017 Small/Medium Commercial Sector ESPI Impact Evaluation,* April 2019. This report discusses the impact evaluation methodology and findings for several high impact small/medium commercial PY2017 electric and gas measures. For this analysis, Guidehouse only used the survey data related to commercial gas fryers. The impact evaluation report can be found here: https://pda.energydataweb.com/#!/documents/2162/view

methodologies (discussed in Section 2.2) are simple yet robust. This approach for conducting an EUL analysis that can provide the foundational framework for leveraging impact evaluation data collection. This EUL analysis approach may be considered for other measures that do not require complex EUL specific research approaches due to its significant cost savings and its simple level of analytical effort.[15]

1.2 Measure Background and Data Availability

Gas fryers have been a standard measure in California for over 20 years. The ex ante EUL value for gas fryers is 12 years, which is the DEER value for all gas commercial kitchen measures.[16] Crucially, the Itron study contains sample populations from Pacific Gas and Electric Company (PG&E) and Southern California Gas Company (SoCal Gas) territories and is the only impact evaluation study with relevant historical data regarding the lifetime of gas fryers. Given the availability of this replacement data, Guidehouse used tracking data from this study to estimate the gas fryer EUL, analyzing the onsite data collection forms and telephone survey responses for data pertaining to gas fryer EUL.

[15] This approach will not capture any change in savings over the life of the technology and just captures the existing definition for EUL.

[16] California Public Utilities Commission, “2008 EUL/RUL Values DEER Update,” http://deeresources.com/files/deer0911planning/downloads/EUL_Summary_10-1-08.xls

2. Study Methodology

2.1 Data Collection

The data used for Guidehouse's analysis was collected as a part of the aforementioned gas fryer studies, and deemed to provide sufficient detail and quality to inform the EUL research study. As such, Guidehouse did not conduct any new data collection efforts.[17] In total, there were 88 completed surveys used in this EUL analysis.

Available data included records of onsite interviews with past program participants, as well as records of telephone surveys. Both the onsite interviews and telephone surveys included questions about the age of replaced equipment, as well as qualitative questions about the type and condition of gas fryers upon replacement and the motivational factors behind each participant's decision-making process. Details of the interviews and surveys are included in the following sections.

In an effort to corroborate findings and expand the available dataset, Guidehouse examined additional gas fryer retrofit data from SoCal Gas to determine its potential relevance to this EUL research. SoCal Gas conducted a data collection effort for several kitchen measures for a series of workpaper updates, including participant surveys and onsite measure installation verifications. While an analysis of EUL was not part of their scope, SoCal Gas did collect information that pertains to EUL, such as fryer age and condition. These additional survey results were based on all food service rebate participants from 2017 and 2018. There were 29 gas fryer sites from the onsite inspections and 49 survey responses; however, only 13 measures from the onsite inspections and 30 measures from the surveys contained information related to the EUL analysis. Ultimately, the dataset was not used in this EUL analysis as there were concerns around the usefulness of the data collected for informing EUL updates, as well as concerns around the low number of sites from the onsite inspections (discussed in Appendix B).

2.1.1 Onsite Surveys

Guidehouse compiled data from 36 onsite survey forms for gas fryers from Itron's 2017 Impact Evaluation Report. The research plan states 43 onsite surveys were completed; however, Guidehouse received valid files from 36 sites since seven of the sites were partial- or full-zero savers. Zero savers are projects that do not save energy. A partial-zero results from "program equipment that are installed and put into service but then are subsequently removed from service – examples include, facility closures, equipment that was observed to be unused, equipment that is no longer in use, and equipment that has been replaced." A full-zero is for "closure immediately following equipment installation, equipment that was observed to be unused, no gas fryer installed, and ineligible equipment verified as installed." [18]

[17] Guidehouse did not find any existing gas fryer EUL studies or gas fryer retention studies when doing preliminary due diligence work.

[18] Itron. Appendix E, *2017 Small/Medium Sector Commercial ESPI Impact Evaluation Report*.

The team compiled survey responses for the questions relevant to EUL into a spreadsheet for further analysis. The questions are outlined in Table 1. Out of the 36 onsites, half included valid, specific data on the question asking how old the equipment was before replacement (the other half responded as “don’t-know”).

Table 1: Onsite Survey Questions

Key Questions	Number of Respondents
Did the new gas fryer replace an existing fryer?	33
Was the replaced fryer a gas or electric fryer?	28
Approximately how old was the fryer that was removed and replaced?	17
How would you describe the removed fryer’s condition?	24
What was the main reason you replaced the existing fryer?	26
At the time of replacement, was the program or rebate important or influential in your decision to replace the existing fryer?	19
If not for the program/rebate, how much longer would you have continued to use the replaced fryer?	20
Were the gas fryer units found to be installed and operable at the time of the onsite inspection?	35

2.1.2 Telephone Surveys

Guidehouse also analyzed 175 telephone interview responses from Itron’s 2017 Impact Evaluation Report. The areas of interest affecting the EUL of gas fryers include qualitative, site-specific gas fryer questions, customer characteristics, and operating hours. Guidehouse compiled the findings in a spreadsheet for further analysis. Out of 175 phone interview responses, 72 contained definitive responses to the question asking how old the equipment was before replacement. Table 2 shows the survey questions that are relevant to this EUL research. Guidehouse verified that the project IDs for the onsite survey dataset and telephone survey dataset were unique. There was one overlapping entry between the two datasets (“claim.id 1105462”). The duplicate telephone response was removed from the dataset during the data cleaning step, resulting in a total count of 71 telephone survey responses.

Table 2: Telephone Interview

Key Questions	Number of Respondents
Did the new gas fryer replace an existing fryer?	101
Approximately how old was the gas fryer that was removed and replaced?	71
How would you describe the removed equipment’s condition?	71

2.2 Modeling Methods

Guidehouse employed several commonly used modeling methods to determine a gas fryer EUL based on the available dataset. This EUL modeling approach complies with the the California Energy Efficiency Evaluation Protocols (EE Evaluation Protocols)[19] chapter titled "Effective Useful Life Evaluation Protocol."

The EE Evaluation Protocol EUL chapter describes the EUL modeling approach when using existing field-collected data.[20] Guidehouse's use of the survey results from the most recent impact evaluation for this EUL research complies with the EE Evaluation Protocols. Additionally, while the EE Evaluation Protocols outline different strategies for EUL research sampling, this analysis leveraged impact evaluation survey data that is already statistically significant.

The chapter from the protocol also instructs evaluators to utilize survival analysis framework in their EUL research.[21] Two modeling methods were considered to analyze the impact evaluation data for determining an updated gas fryer EUL value. Guidehouse chose the Weibull distribution survival curve and the Kaplan-Meier analysis for each method's ability to uniquely handle product survival data (discussed below).

This EUL analysis approach may be considered for other EUL research in future studies for measures that do not require a complex EUL-specific research approach, due to its significant cost savings and its simple level of analytical effort.

2.2.1 Gas Fryer Survival Analysis – Weibull Distribution

The Weibull probability distribution function is widely used in survival analysis. It takes on characteristics from other distribution types by modifying the shape and scale parameters. These parameters were empirically determined[22] by running the impact analysis EUL data through a maximum likelihood estimation analysis software.[23] Details of the shape and scale parameters follow:

- **β**, the shape parameter—also referred to as the slope parameter—defines the overall shape of the distribution curve. The curve fitting process involves determining the numerical representation of the shape parameter in order to generate the optimal best-fit

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[19] *California Energy Efficiency Evaluation Protocols: Technical, Methodological, and Reporting Requirements for Evaluation Professionals*, April 2006, http://www.cpuc.ca.gov/WorkArea/DownloadAsset.aspx?id=5212

[20] EE Evaluation Protocols: p. 120. "Evaluators are expected to develop a plan for estimating survival functions for measures included in the scope of their work."

p. 125. "many functional forms of survival analysis models ("model functional forms") can be tested with available survival analysis statistical programs. The regression techniques available allow consideration of right-censored data and can handle continuous time data, discrete time data, and other types of data."

[21] "The objective of the EUL analysis studies is to estimate the ex post EUL, defined as the estimate of the median number of years that the measures installed under the program are still in place, operable, and providing savings. Evaluators are expected to develop a plan for estimating survival functions for measures included in the scope of their work. " California Energy Efficiency Evaluation Protocols Document, p. 120.

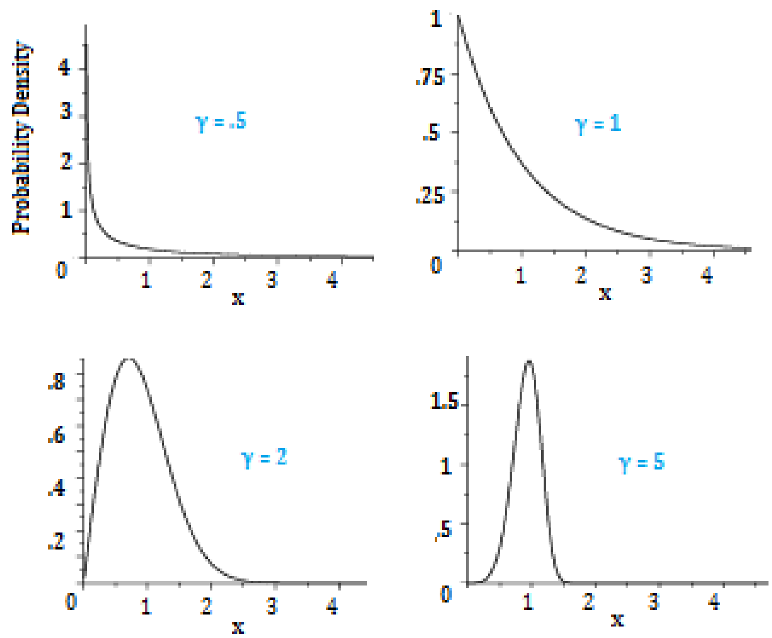
[22] Delignette-Muller ML and Dutang C (2015), "fitdistrplus: An R Package for Fitting Distributions." *Journal of Statistical Software*, 64(4), p. 1-34.

[23] Maximum likelihood estimation consists of finding the values of the distribution parameters that maximize the log-likelihood of the data values.

distribution graph. Figure 1 illustrates the impact on the Weibull distribution when changing the shape parameter. One of the reasons for the popularity of the Weibull distribution is that it includes other useful distributions as special cases or close approximations. For example:

- If β = 1, the Weibull distribution is identical to the exponential distribution.
- If β = 2, the Weibull distribution is identical to the Rayleigh distribution.
- If β = 2.5, the Weibull distribution approximates the lognormal distribution.
- If β = 3.6, the Weibull distribution approximates the normal distribution.

Figure 1: Impacts of Adjusting the Shape Parameter on the Weibull Probability Distribution



Note: The above figure is an illustrative example of the impacts on a distributions shape from adjusting the shape parameter. The values in these four graphs are not based on the gas fryer EUL data.

Typically, the value of β ranges between 0.5 and 8.0. Guidehouse determined and used the shape parameter that most accurately models the change in existing fryer removals.[24]

- **η**, the scale parameter, defines the width (or number of years in the case of this EUL analysis) of the distribution function. Increasing the scale parameter while holding the shape parameter constant stretches out the probability distribution function while

[24] Using the fitdistcens function in the fitdistrplus library package in R, Guidehouse determined the scale parameter to be 10.9 +/- 0.5 and the shape parameter to be 3.9 +/- 0.5 within one standard deviation.

simultaneously decreasing its peak. However, it does not change the actual shape of the distribution.

Using both the shape parameter and the scale parameter, the Weibull probability distribution function and the associated median value—which is used to determine the EUL—are given by equations where *t* represents time in years:

$$f(t) = \frac{\beta}{\eta}\left(\frac{t}{\eta}\right)^{\beta-1} e^{-\left(\frac{t}{\eta}\right)^{\beta}} \qquad \text{(eq 1.)}$$

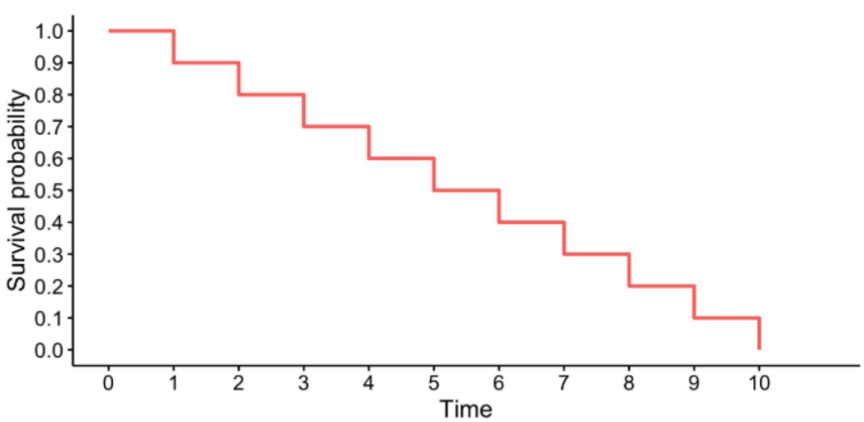
$$\text{median value} = \eta * \ln 2^{\frac{1}{\beta}} \qquad \text{(eq 2.)}$$

2.2.2 Gas Fryer Survival Analysis – Kaplan-Meier Estimator

In addition to the Weibull distribution, the Kaplan-Meier analysis is another modeling method used in survival analysis of lifetime data. The two analyses were not combined in this analysis, but instead used as a graphical overlay—the Kaplan-Meier results are shown along with the Weibull distribution to visually confirm that the distributions align and to corroborate the final result.

To generate a Kaplan-Meier chart, the fryer's operational status ("Is the gas fryer installed and operating?") and the time between observations must be known. For example, if a given fryer is known to be installed at year 5 but is not installed at year 10, the fryer was necessarily removed within that timeframe. The Kaplan-Meier plot is a series of declining horizontal steps which approximate the survival function. Figure 2 provides an illustrative example of what a Kaplan-Meier curve looks like. As a sample size increases and the time period between EUL observations decreases, the Kaplan-Meier methodology approaches the real theoretical survival curve. The Kaplan-Meier analysis is useful visual representation of the actual observation data, compared to best fit distribution curves which generate a smooth curve that is a best approximation of the scattered data points.

Figure 2: Illustrative Kaplan-Meier Curve



Note: The above figure is an illustrative example of the Kaplan-Meier survival curve. The values in this graph are not based on the gas fryer EUL data.

The Kaplan-Meier survival curve may introduce some numerical bias because it does not account for the fact that failures likely occur after the point when the data is collected. In other words, it is not known when an existing fryer would have failed on its own had it not been replaced due to a rebate incentive program. In statistical literature, these cases are known as right-censored. As a result, analyses that do not account for right-censored data, such as the Kaplan-Meier approach, cannot accurately inform any EUL-related information beyond the furthest recorded observation.[25] For this reason, persistence analysis best practices—such the best-fit Weibull distribution software tools utilized in this study—use survival analysis methods that account for right-censored data, so one can predict the likelihood that a given technology will reach a certain age, even if that age is greater than what was collected in the sample data.[26]

2.2.3 Survey Response and Onsite Inspection Data Cleaning and EUL Analysis Steps

The following outlines the steps used to analyze the 2017 impact evaluation survey results and to determine the overall EUL for gas fryers based on the existing dataset.

2.2.3.1 Step 1: Filter out non-applicable data from the 2017 evaluation site visit and phone survey data.

The original survey asked respondents to choose from the following bins when determining their existing fryer's age:

- 0 – 5 years
- 5 – 10 years
- 10 – 15 years
- 15+ years
- Exact age (onsite survey only)

Despite the presence of an option to insert the exact age for the onsite survey, only three respondents provided exact estimates. Therefore, in order to run a best-fit analysis to determine a representative Weibull distribution's shape and scale parameters, Guidehouse used additional survey answers from the same respondent (e.g., "What was the fryer's condition when replaced?") to adjust these raw age bins to reflect a narrower age range estimate (discussed at length below).

Before adjusting the individual fryer EUL bin estimates (referred to as bin estimates), Guidehouse screened out several of the phone survey responses and the onsite data as not

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[25] "…Estimating the mean or median when data are right-censored can provide a biased estimate. Classic survival analysis techniques have been developed that account for this right censorship in the data and are able to provide unbiased estimates." California Energy Efficiency Evaluation Protocols Document, p. 124.

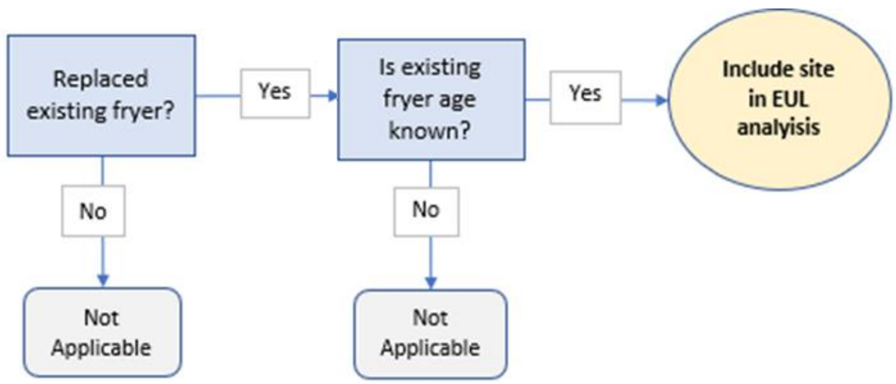
[26] Scholz, Fritz. "Weibull Reliability Analysis." *Boeing Phantom Works Mathematics & Computing Technology*, 1999, faculty.washington.edu/fscholz/Reports/weibullanalysis.pdf.

applicable for the EUL analysis (Figure 3). The reasons that responses were screened out included:

1. The new fryer did not replace an existing fryer.
2. The exact age or the bin estimates of the existing fryer was not specified.

Of the original 175 phone responses and 36 onsite-survey total responses, 71 phone responses and 17 onsites were suitable for the Weibull uncertainty analysis.[27]

Figure 3: Initial Screen Survey Logic



Note: The phone surveys did not ask if the existing fryer was electric or gas. Guidehouse assumed that all sampled sites were applicable for gas fryers.

After the initial responses were screened, Guidehouse analyzed the responses to the key survey questions outlined in Table 1 and Table 2 to adjust the individual fryer bin estimates. In order to fit a Weibull distribution, the bin EUL range estimates required transformation according to the following scenarios:

1. **Scenario 1 – Interval Censored Data**

   If secondary survey questions confirmed that the existing fryer was no longer installed or stated when the facility would have removed it, the fryer's EUL can be confidently assumed to be within a certain range. For example, if a participant indicated that their existing fryer was 5-10 years old when they participated in the program, but that they would have replaced it in 2-3 years, the fryer's EUL is in the range of 5 – 13 years. Next, Guidehouse looked at the remaining survey questions to determine if the lower end of the bin estimate could be adjusted to create a tighter interval. For this same example:

   - If the participant stated that their fryer was replaced as part of general facility upgrade, would have been replaced in 2 - 3 years or was in good working condition when removed, the mid value of the 5 to 10 year bin was assigned as the new lower bound, for a final EUL range of 7.5 to 13 years.
   - If a participant stated their fryer was replaced as part of a facility upgrade/was in good working condition when removed and that they would have replaced it in

[27] Guidehouse verified that the project IDs for the onsite survey dataset and telephone survey dataset were unique. There was one overlapping entry between the two datasets ("claim.id 1105462"). The duplicate telephone response was removed from the dataset during the data cleaning step.

2-3 years, then the upper value of 10 was assigned as the new lower bound for a final EL range of 10 to 13 years.

Figure 5 and Figure 6 detail the decision logic used for adjusting these individual site's bin estimates.

2. **Scenario 2 – Right-Censored Data**

   For sites that might have continued to use a fryer beyond the upper end of the bin estimate in the absence of an incentive program, an upper EUL bound could not be determined (i.e., the site did not state how many years they would have continued to use the fryer were it not for the program), and Guidehouse could not generate a definitive upper bound for the EUL range estimate. These responses are marked as right-censored, as there is uncertainty as to the value of the upper end of that fryer's bin estimate. Guidehouse's analysis approach using a right-censored distribution is particularly well-suited to analyzing this kind of data and accounting for the uncertain lifespan of such equipment.

Unlike the Kaplan-Meier analysis, the Weibull distribution analysis can account for right-censored and interval censored data when generating a best fit distribution curve.[28] By accounting for both of these scenarios, the generated Weibull distribution curve is a combination of sites where fryers that were no longer operating and for sites that may have continued to use their fryers had it not been for the program incentive. Appendix A shows the full results from age bin adjustments compared to the raw survey age bin estimates.

Figure 4 through Figure 7 illustrate the decision logic used to adjust a given site's age bins for the phone and onsite survey respondents. The blue boxes are the survey questions and the white boxes are the response options for those questions. The ovals represent what adjustment was made to the age bin estimate in response to each question and answer. The adjustment options include:

1. Age bin estimate = Max. Adjust the site's bin estimate to be the maximum of that range. For example, if a respondent stated that their fryer was 0-5 years in age when removed, but it was not operable when the rebated fryer was installed, the participant would not have continued using the existing fryer in the absence of the rebate program (i.e., the fryer definitively reached its EUL sometime in the 0-5 year range). Therefore, assume that existing fryer had a maximum EUL of 5 years (no adjustment).
2. Age bin estimate = Mid. Adjust the site's bin estimate to be the middle of that range. For example, if a respondent stated that their fryer was 0-5 years in age when removed, but it was still in good condition when removed, update the lower end of the bin estimate to 2.5 years as it is fairly certain that even if the fryer was less than one year old when removed, it would have continued to be utilized for several years.

[28] Delignette-Muller ML and Dutang C (2015), "fitdistrplus: An R Package for Fitting Distributions." *Journal of Statistical Software*, 64(4), 1-34.

3. Age bin estimate = Min. Adjust the lower end of the bin estimate to be the minimum of that range. For example, if a respondent stated that their fryer was 0-5 years in age when removed, but it was not installed and operational at the time of the inspection, it cannot be assumed that the fryer was not removed in the first year. Therefore, the lower range should not be adjusted.
4. Age bin estimate = No Change. The upper or lower ends of the bin estimates cannot be changed based on that question.
5. Age bin estimate = Custom. Change the upper or lower end of the bin estimate according to a definitive custom response.

The resulting bin adjustments from the onsite surveys and the phone surveys were then combined into one dataset.

Figure 4 shows the logic used to adjust the lower range of the existing fryer bin estimate from the onsite inspection data. For example, if a respondent indicated that their fryer was 10-15 years old when replaced, then Figure 4 outlines the analysis used to determine if the 10 value should be adjusted based on the additional information collected.

Figure 4: EUL Onsite Survey Response, Lower Bin Estimate Adjustment Logic

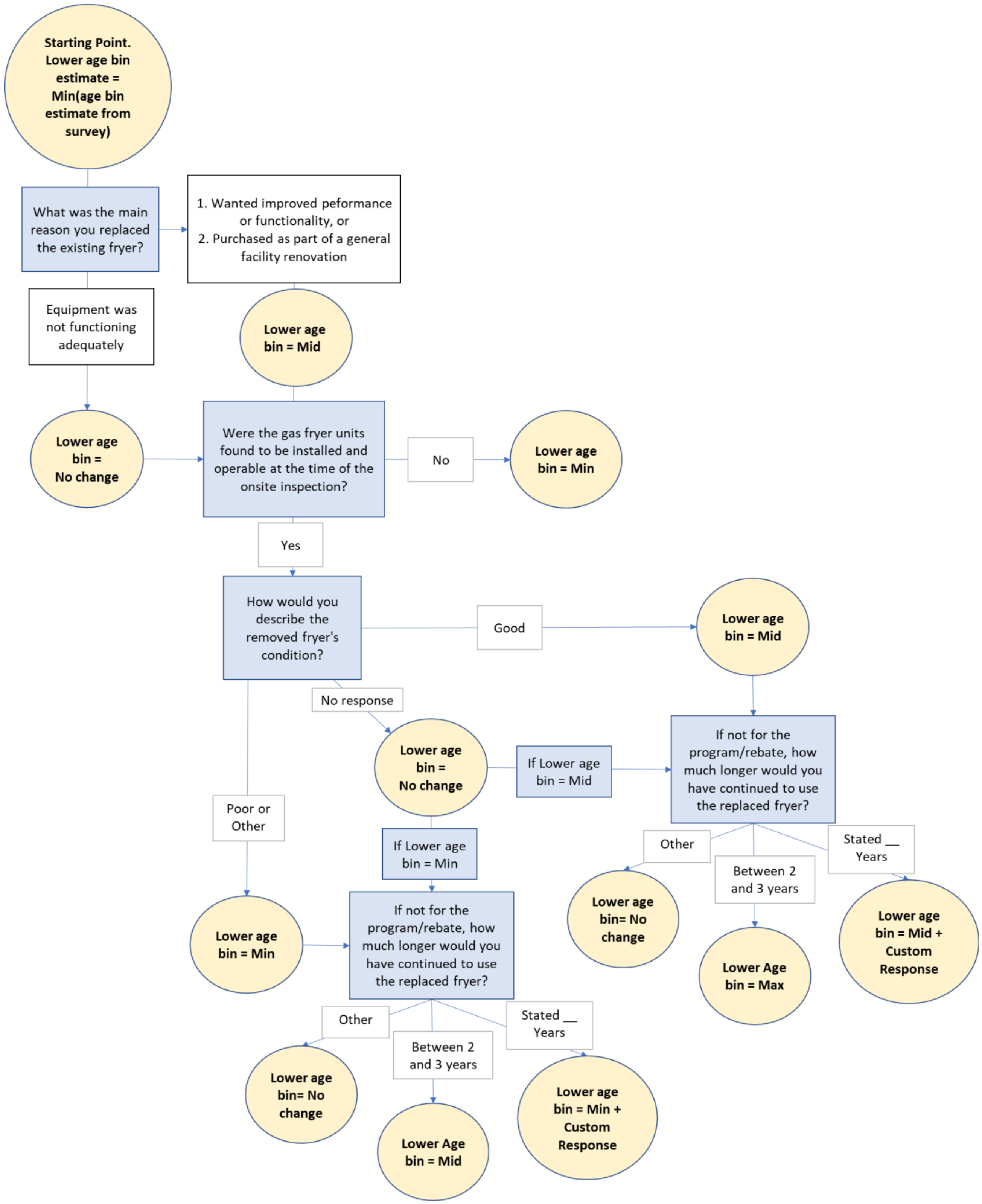
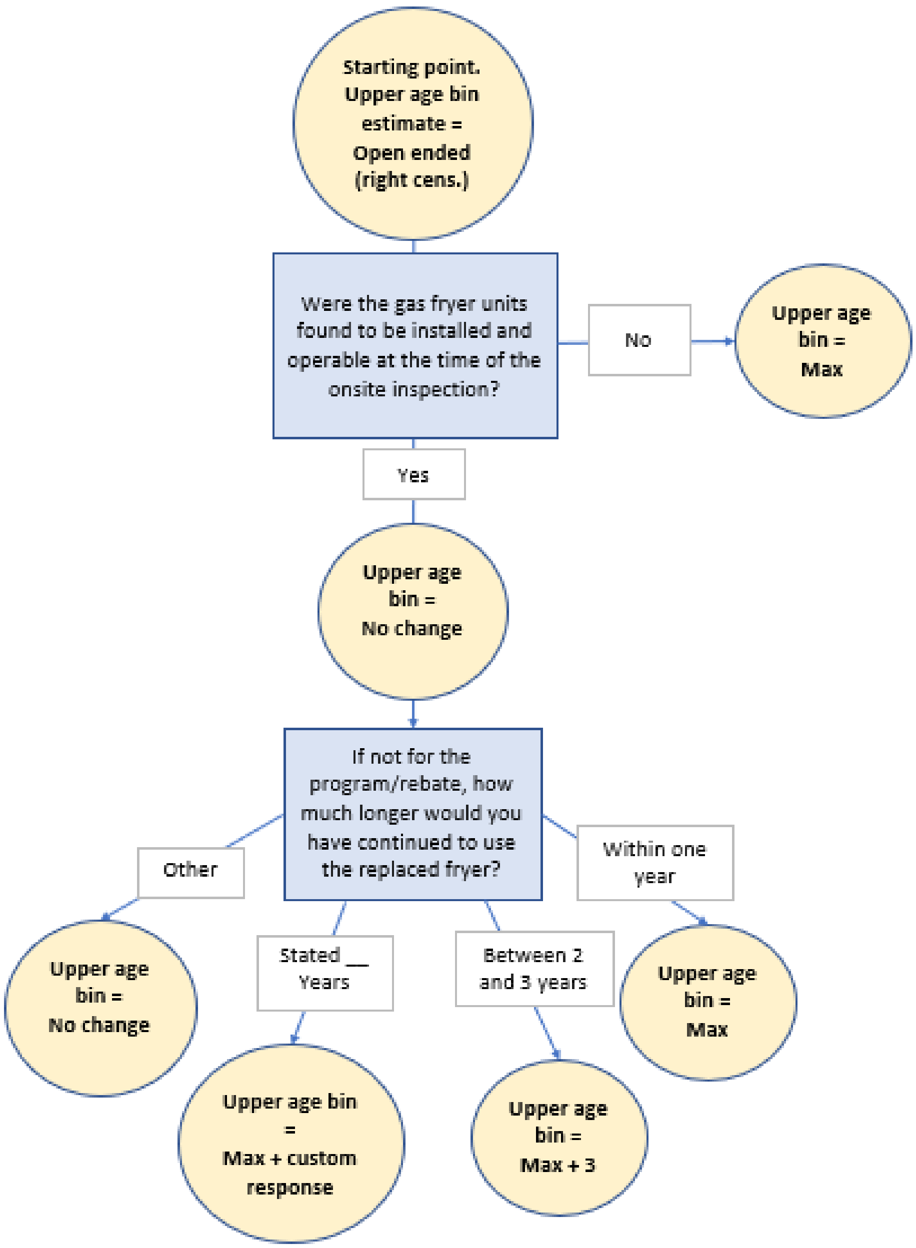


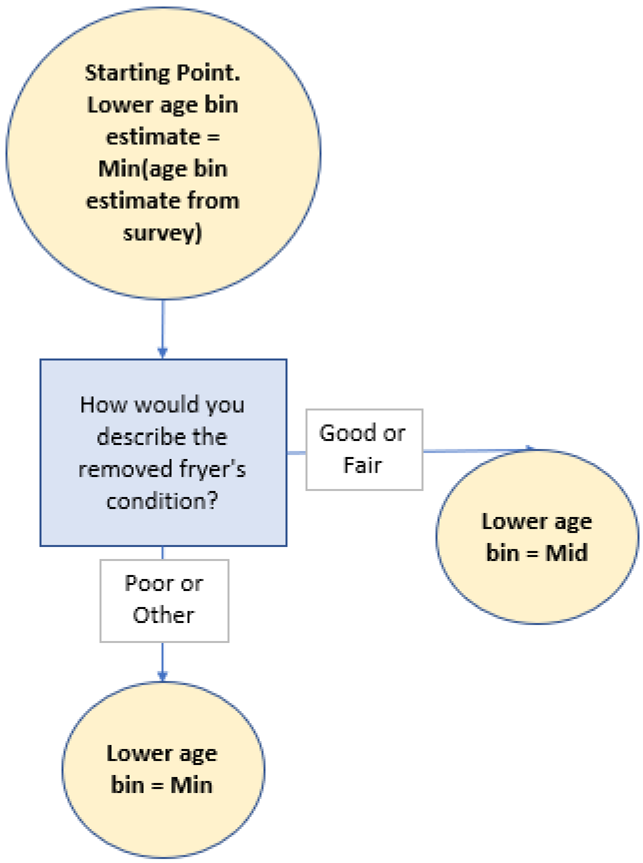
Figure 5 shows the logic used to adjust the upper range of the existing fryer bin estimate from the onsite inspection data. For example, if a respondent indicated that their fryer was 10-15 years old when replaced, then Figure 5 outlines the analysis used to determine if the 15 value should be adjusted based on the additional information collected.

Figure 5: EUL Onsite Survey Response, Upper Bin Estimate Adjustment Logic



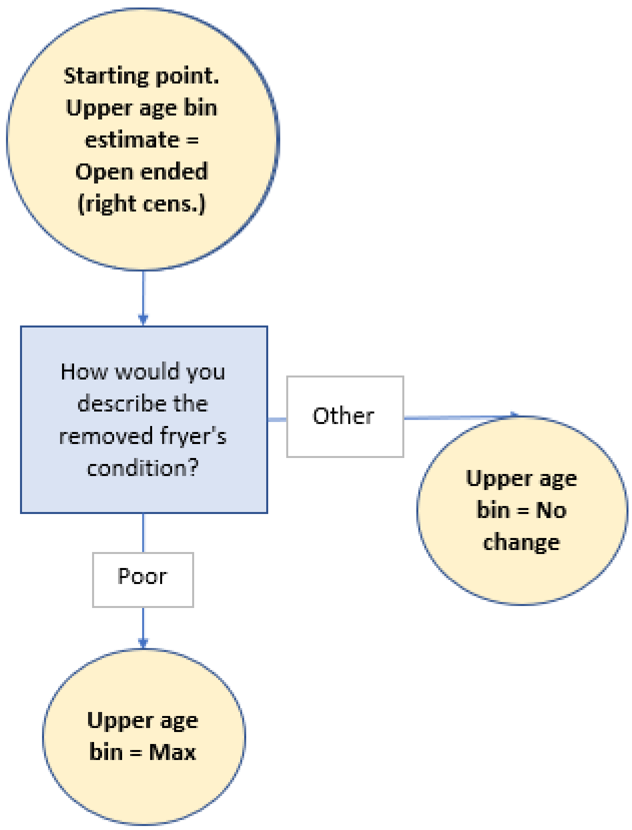
In a process similar to that used for site visit results, Figure 6 shows the logic used to adjust the lower range of the existing fryer bin estimate from the phone survey responses. For example, if a respondent indicated that their fryer was 10-15 years old when replaced, then Figure 6 outlines the analysis used to determine if the 10 value should be adjusted based on additional information collected.

Figure 6: Phone Interview Screening Logic, Lower Bin Estimate Adjustment Logic



Similarly, Figure 7 shows the logic used to adjust the upper range of the existing fryer bin estimate from the phone survey responses. For example, if a respondent indicated that their fryer was 10-15 years old when replaced, then Figure 7 outlines the analysis used to determine if the 15 value should be adjusted based on the additional information collected. For the upper bound, unless a site indicated their fryer was in poor condition, the upper limit of that fryer's EUL age bin could not be confidently stated and was left as open ended (i.e., right censored data).

Figure 7: Phone Interview Screening Logic. Upper Bin Estimate Adjustment Logic



2.2.3.2 Step 2: Use the compiled survey data to generate a best-fit Weibull distribution to determine the gas fryer survival curve.

After transforming the initial bin estimates into interval-censored or right-censored data points, Guidehouse conducted a best-fit analysis using maximum likelihood estimation methods on the stacked EUL data to generate the representative Weibull distribution curve. Using this distribution curve, Guidehouse determined the median gas fryer value. The Weibull probability distribution function and cumulative distribution function illustrate the likelihood that a fryer is still operable and installed at a given year. [29]

2.2.3.3 Step 3: Determine the median value for the recommended gas fryer EUL.

Guidehouse calculated the median value from the Weibull curve (Equation 2). This serves as the estimated value for gas fryer EULs.

[29] The cumulative distribution function, defined as $1 - \int_0^t (Weibull\ PDF) dt$, shows what fraction of the entire product population has reached their EUL. At time = 0, no fryers have failed and the cumulative PDF equals 1. As time increases, the value approaches zero indicating that all gas fryers in a population will have reached their EUL.

3. Results

3.1 Impact Evaluation Survival Analysis

This section presents the overall results of the Weibull survival analysis. Figure 8 shows the distribution of the raw survey and onsite bin estimates after filtering out non-applicable responses, as well as the distribution of bin estimates after the EUL adjustment step (see Appendix A for the full list of raw survey responses and adjusted EUL values for the Weibull distribution fitting). More than 50 of the 88 total responses (after removing the one duplicate site between the survey data and onsite inspections) stated that their existing gas fryer was between 5-10 years old when the new fryer was installed. After adjusting the individual EULs based on other same-respondent survey responses, the total number of fryers in the 10-to-15-year range estimate increased while the number of fryers in the 5-to-10-year range decreased. The amount in the 0-to-5-year and the 15+ range stayed the same.

Figure 8: Distribution of Raw and Adjusted Survey Responses

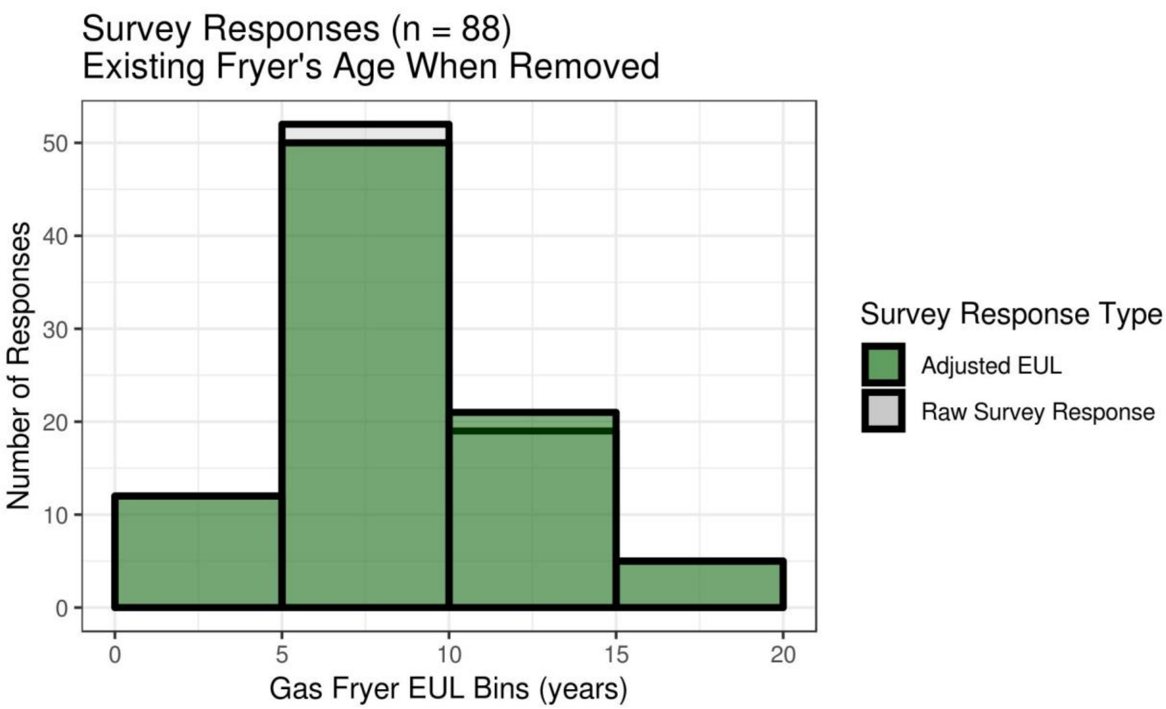


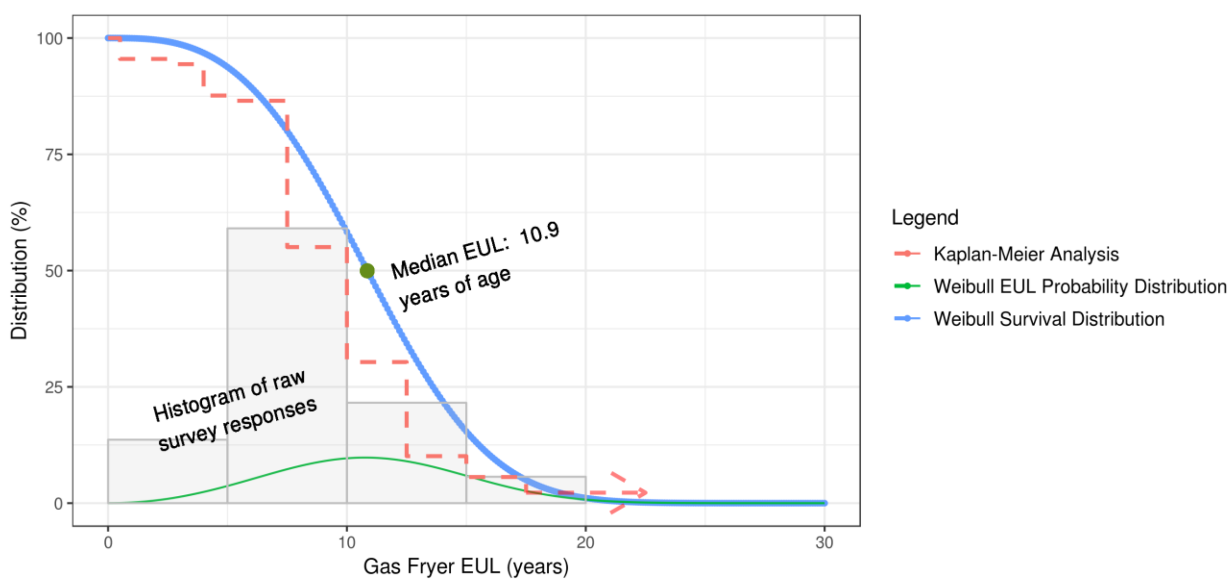
Figure 9 compares the results of both the Weibull uncertainty analysis and the Kaplan-Meier analysis:

- The Kaplan-Meier analysis, in red, visually represents the survivability distribution (stair-step lines) of EUL values after adjusting the raw responses.
- The histogram from Figure 8 (grey boxes) serves as a visual reference, although the y axis in that case is percentage of total responses.
- The green line is the probability distribution function results.
- The blue line is the cumulative distribution function results, also known as the survival curve.

Both the survival curve and the probability distribution function are skewed to the right of the Kaplan-Meier curve and the histogram of raw survey data. This is to be expected as the histogram and Kaplan-Meier chart do not account for right-censored data, while the Weibull functions do.

The median EUL of this dataset is 10.9 years.[30] This value is statistically different from the currently used value of 12 years, which is the standard EUL for all commercial kitchen measures.

Figure 9: Gas Fryer Survival Curve



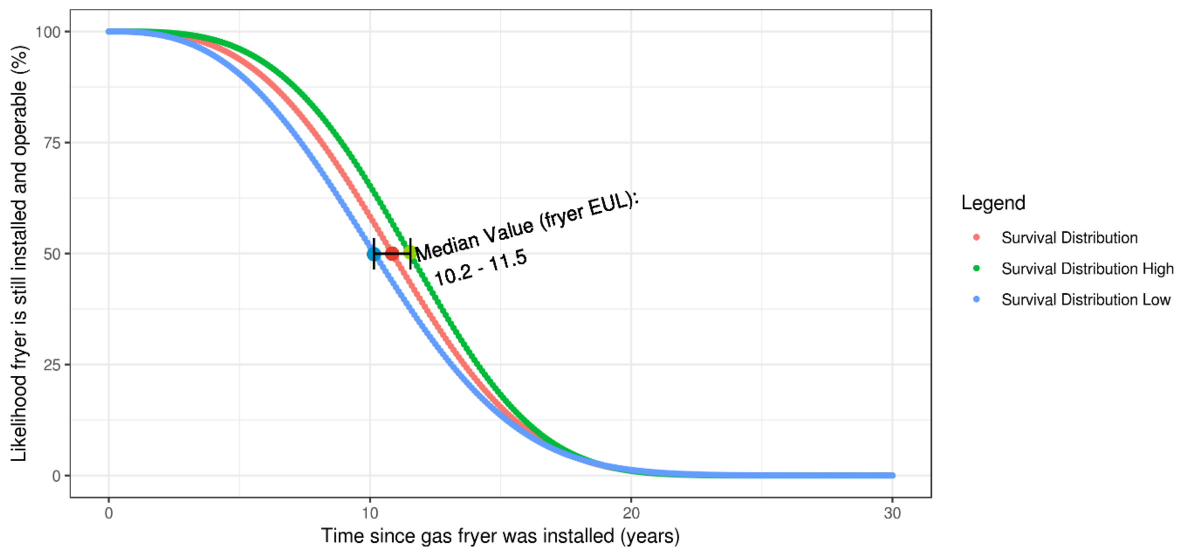
As any such study should also examine the potential for error and/or uncertainty, Figure 10 shows the uncertainty bounds for the Weibull cumulative distribution. Unlike with typical survey

[30] The total population size for the 2017 gas fryer evaluations was 1,623 for onsites and 2,385 for telephone surveys, while the number of completed surveys was 71 for phone surveys and 17 for onsites. Because this study leverages impact evaluation survey data that is already statistically significant, a new statistical sample was not determined.

analysis, the standard deviation from the Weibull analysis is a result of modeling error, not sampling error. This analysis leverages the impact evaluation results, which met the sampling precision requirements outlined in the EE Evaluation Protocols.[31] With sampling error, results are often expressed in terms of confidence intervals at relative precisions. However, when modeling uncertainty the confidence intervals are instead presented at plus or minus one standard deviation instead of relative precisions.

Increasing and decreasing the Weibull shape and scale parameters by one standard deviation results in a median EUL within 10.2 to 11.5 years, which still maintains a relatively tight EUL estimate window and further definitively suggests a difference from the existing EUL of 12 years.

Figure 10: Gas Fryer Survival Curve Uncertainty Estimates



[31] California Energy Efficiency Evaluation Protocols: Technical, Methodological, and Reporting Requirements for Evaluation Professionals, April 2006, http://www.cpuc.ca.gov/WorkArea/DownloadAsset.aspx?id=5212. EE Evaluation Protocols. p. 46-47. “All engineering-based methods must use a combination of deemed and measured data sources with sufficient sample sizes designed to meet a 30% error tolerance level in the reported value at a 90% confidence level to meet the Basic rigor level and a 10% error tolerance level at a 90% confidence level for the Enhanced rigor level.”

4. Conclusions

Guidehouse used the 2017 impact evaluation results to generate a gas fryer survival curve resulting in a gas fryer EUL of 11 years, slightly lower than the current gas fryer EUL of 12 years—a non-specific value that is the same across all commercial kitchen gas measures. Guidehouse employed a Weibull uncertainty analysis—a simple yet robust methodology that can be implemented across other measure types that have similar EUL-related survey data. Instead of conducting cost-intensive primary research, Guidehouse utilized the survey results from the most recent impact evaluation. This EUL analysis approach may be considered for other measures that do not require complex EUL specific research approaches due to its significant cost savings and its simple level of analytical effort. Future evaluation plans may want to consider tightening the range bins questions when asking about the existing equipment's age before removal (e.g., decreasing the range from 5 years to 3 years) as well as encourage respondents to look up the exact installation date of the existing equipment when applicable.

In addition, future evaluators may want to better understand how a measure's EUL is impacted by other persistence factors, such as facility operating hours, renovation cycles, facility type, etc. Future evaluation and EUL related surveys should consider:

- Increasing the number of surveys conducted
- Including more persistence-related topics to better assess what is impacting the EUL

For example, in this study, Guidehouse attempted to understand if the EUL for gas fryers could be differentiated by kitchen type (e.g., chain restaurant vs. individually owned restaurant) or by hours of use. Unfortunately, the team could not draw any quantitative results based on the limited number of completed surveys.

Another limitation with this study is that the data was limited to historical program results. There is a risk that new gas fryers that are being installed will have a longer lifetime than the previous generation; however, Guidehouse believes that this risk is minimal given that the Energy Star standard (Table 3)—which serves as minimum standard for the gas fryer measure—has not significantly changed for the last 10 years. In addition, Guidehouse assumed that facilities did not change their fuel type when replacing their fryers (i.e., existing gas fryers were replaced by new gas fryers). Future data collection efforts should attempt to capture the fuel type of the existing as well as the new equipment.

Table 3: ENERGY STAR Program Requirements for Commercial Open Deep-Fat Fryers

Efficiency Year and Requirement	Standard Gas Fryers	Standard Electric Fryers	Large Vat Gas Fryers	Large Vat Electric Fryers
2003: Heavy-Load Cooking Energy Efficiency	> 50%	> 80%	Cooking efficiency not split between fryer type	
2003: Idle Energy Rate	< 9,000 Btu/hour	< 1,000 W	Idle energy rate not split between fryer type	
2011: Heavy-Load Cooking Energy Efficiency	> 50%	> 80%	> 50%	> 80%
2011: Idle Energy Rate	< 9,000 Btu/hour	< 1,000 W	< 12,000 Btu/hour	< 1,100 W
2016: Heavy-Load Cooking Energy Efficiency	> 50%	> 83%	> 50%	> 80%
2016: Idle Energy Rate	< 9,000 Btu/hour	< 800 W	< 12,000 Btu/hour	< 1,100 W

The ENERGY STAR program requirements and testing procedures for commercial gas fryers have not changed over the last 7 years. Standard Fryers: ASTM Standard F1361-07 (2013), Test Method for Performance of Open Deep Fat Fryers Large Vat Fryers: ASTM Standard F2144-09, Test Method for Performance of Large Open Vat Fryers

Source: ENERGY STAR program requirements for commercial fryers Version 2 and Version 3.

Appendix A. Impact Evaluation EUL Data

Table A-1: Total Impact Evaluation Adjusted EUL Range Estimates for the Weibull Analysis

Site Number	Survey Type	Censor Type	Raw Survey Response – Bin Range Selection		Adjusted Bins for Weibull Analysis	
			Lower Bin	Upper Bin	Lower EUL	Upper EUL
1	Onsite Inspection	Interval	10	15	10	15
2	Onsite Inspection	Interval	5	10	5	10
3	Onsite Inspection	Interval	5	10	5	10
4	Onsite Inspection	Interval	0	5	0	5
5	Onsite Inspection	Interval	5	10	7.5	10
6	Onsite Inspection	Interval	5	10	7.5	10
7	Onsite Inspection	Interval	10	15	10	15
8	Onsite Inspection	Interval	10	15	10	15
9	Onsite Inspection	Interval	0	5	2.5	5
10	Onsite Inspection	Interval	0	5	2.5	5
11	Onsite Inspection	Interval	5	10	10	13
12	Onsite Inspection	Interval	5	10	5	10
13	Onsite Inspection	Uncensored	4	4	4	4
14	Onsite Inspection	Uncensored	0.5	0.5	0.5	
15	Onsite Inspection	Interval	5	10	5	5
16	Onsite Inspection	Interval	0	5	10	15
17	Onsite Inspection	Interval	10	10	10	10
18	Survey	Interval	5	10	7.5	
19	Survey	Interval	5	10	7.5	
20	Survey	Interval	5	10	7.5	
21	Survey	Interval	10	15	10	15
22	Survey	Interval	10	15	10	15
23	Survey	Interval	10	15	10	15
24	Survey	Interval	5	10	5	
25	Survey	Interval	5	10	5	
26	Survey	Interval	5	10	5	
27	Survey	Interval	5	10	5	
28	Survey	Interval	5	10	5	
29	Survey	Interval	5	10	5	
30	Survey	Interval	5	10	5	

Site Number	Survey Type	Censor Type	Raw Survey Response – Bin Range Selection		Adjusted Bins for Weibull Analysis	
			Lower Bin	Upper Bin	Lower EUL	Upper EUL
31	Survey	Interval	5	10	5	
32	Survey	Interval	10	15	12.5	
33	Survey	Interval	10	15	12.5	
34	Survey	Interval	10	15	12.5	
35	Survey	Interval	5	10	5	10
36	Survey	Interval	5	10	5	10
37	Survey	Interval	15	20	15	20
38	Survey	Interval	10	15	12.5	
39	Survey	Interval	5	10	5	10
40	Survey	Interval	5	10	7.5	
41	Survey	Interval	10	15	10	15
42	Survey	Interval	0	5	0	5
43	Survey	Interval	5	10	5	10
44	Survey	Interval	5	10	5	10
45	Survey	Interval	0	5	0	
46	Survey	Interval	0	5	2.5	
47	Survey	Interval	5	10	7.5	
48	Survey	Interval	15	20	17.5	
49	Survey	Interval	5	10	5	10
50	Survey	Interval	0	5	2.5	
51	Survey	Interval	0	5	2.5	
52	Survey	Interval	5	10	5	10
53	Survey	Interval	5	10	5	10
54	Survey	Interval	5	10	5	10
55	Survey	Interval	5	10	5	10
56	Survey	Interval	5	10	5	10
57	Survey	Interval	5	10	5	10
58	Survey	Interval	5	10	5	10
59	Survey	Interval	5	10	5	10
60	Survey	Interval	0	5	2.5	
61	Survey	Interval	10	15	10	15
62	Survey	Interval	15	20	15	20
63	Survey	Interval	5	10	7.5	
64	Survey	Interval	10	15	10	15
65	Survey	Interval	5	10	7.5	

Site Number	Survey Type	Censor Type	Raw Survey Response – Bin Range Selection		Adjusted Bins for Weibull Analysis	
			Lower Bin	Upper Bin	Lower EUL	Upper EUL
66	Survey	Interval	5	10	7.5	
67	Survey	Interval	5	10	7.5	
68	Survey	Interval	5	10	7.5	
69	Survey	Interval	5	10	7.5	
70	Survey	Interval	15	20	17.5	
71	Survey	Interval	5	10	7.5	
72	Survey	Interval	5	10	7.5	
73	Survey	Interval	5	10	7.5	
74	Survey	Interval	5	10	7.5	
75	Survey	Interval	10	15	10	15
76	Survey	Interval	10	15	10	15
77	Survey	Interval	10	15	10	15
78	Survey	Interval	10	15	10	15
79	Survey	Interval	10	15	10	15
80	Survey	Interval	5	10	7.5	
81	Survey	Interval	5	10	7.5	
82	Survey	Interval	5	10	7.5	
83	Survey	Interval	5	10	7.5	
84	Survey	Interval	5	10	7.5	
85	Survey	Interval	15	20	15	20
86	Survey	Interval	10	15	10	15
87	Survey	Interval	5	10	5	10
88	Survey	Interval	5	10	5	10

Appendix B. SoCal Gas Food Service Work Paper Update

SoCal Gas conducted a data collection effort for several kitchen measures for a series of workpaper updates, including participant surveys and onsite measure installation verifications. While an analysis of EUL was not part of their scope, SoCal Gas did collect information that pertains to EUL, such as fryer age and condition. SoCal Gas's onsite inspection and online surveys were based on all food service rebate participants from 2017 and 2018. Theoretically, the SoCal Gas data may overlap with the impact evaluation data.

Onsite Inspections

SoCal Gas conducted onsite inspections for 110 kitchen rebate program participants. Of these, 29 installed gas fryers as part of the rebate program. As with the impact evaluation data, these onsite inspections asked if the program participants had an existing fryer and if so, how old it was before being removed.

After filtering sites for applicable responses, only 13 responses remained. Zero respondents indicated their fryer was less than 5 years of age when removed, eight respondents indicated their fryer was less than 10 years of age, one respondent stated their fryer was less than 15 years and four respondents indicated their fryer was greater than 15 years old when removed.

Survey Responses

SoCal Gas also surveyed additional gas fryer rebate program participants. They conducted 96 surveys for various kitchen measures program participants, of which 49 indicated they had an existing fryer. After filtering for applicable responses, there were 30 existing fryer age estimates. Twenty-eight respondents indicated that their fryer was less than 5 years of age when removed, seven respondents indicated their fryer was less than 10 years of age, and only two respondents indicated their fryer was greater than 10 years old when removed.

Ultimately, the SoCal Gas data was not included as part of this gas fryer EUL analysis for the following reasons:

- **Large distribution of range estimates:**

  The onsite inspections had over 50% of respondents answer 5-10 years and another 25% answer 15+ years. Meanwhile, no sites answered 0-5 years and only one site selected 10-15 years. This non-uniform distribution of responses combined with the low number of sites inspected results in a distribution with two relative peaks in the 0-to-5-year range and 15+ year range. This behavior is atypical of survival data, which usually has one central peak.

- **High affinity of right-censored data:**

  Unlike with impact evaluation data, there was limited additional data captured that could be used to confirm the upper limit of the EUL range estimates. With the impact evaluation Weibull analysis, 48 of 88 sites were not right-censored. Meanwhile with the SoCal Gas data, all but three sites out of 43 sites were right-censored, meaning that the upper EUL range estimate on the rest of the data points could not be confirmed.[32] While the Weibull distribution analysis can incorporate right-censored data, the accuracy of the best-fit approximation greatly improves with an increased number of interval censored and non-censored data points. When the right-censored data makes up a larger percentage of the Weibull distribution data, the model has fewer certain data points (i.e., the interval censored data) with which to characterize the likely behavior of uncertain data points (i.e., the right censored data).

Guidehouse reran the model results with the assumption that the SoCal Gas data and the impact evaluation data did not have any overlapping sites and thus could be stacked. Under this scenario, the model resulted in a recommended EUL value of 8.5 years with a confidence range of 0.8 years. The inclusion of the SoCal Gas data decreases the recommended EUL and increases the confidence interval. Ultimately, Guidehouse decided to only include the impact evaluation data since the SoCal Gas data was highly uncertain, could not be ruled out as duplicate data (i.e., there is a chance some of the SoCal Gas sites were also part of the impact evaluation) and did not include secondary questions (i.e., fryer condition) that could improve the model inputs.

[32] For three of the sites from the SoCalGas data, Guidehouse was able to conclude that the fryer was no longer in operation when the rebated fryer was installed based on secondary information from the site-specific notes.

Appendix C. Comments

After posting the gas fryers EUL report, the CPUC received comments only from SoCal Gas. The SoCal Gas comments are addressed as follows:

Comment 1) Page 17 Section 2.2.3 – In the "Scenario 1 – Interval Censored Data" subsection, Guidehouse states that if a respondent answered that they would have replaced their equipment in 2-3 years after participating in the program, then the upper bound of the fryer's effective useful life ("EUL") should increase by 3 years. SoCalGas suggests that the equipment could still be functional beyond that additional time (i.e. 2-3 years in the example), if still in good working condition, and should be factored into the analysis.

Guidehouse Response: This comment may reflect the difference between official 'EUL' value and 'technical life'. Because the equipment would be removed by the current user, it will incur no further savings for the current user after its removal, regardless of it the equipment is still functional or not. We believe that the analysis is correct in assigning no further savings after initial removal, even if the equipment may later be sold as used.

Comment 2) Page 17 Section 2.2.3 – In the same subsection as above, the mid value of the initial EUL range replaces the lower bound of the range if a respondent answered with one of three possible choices. There is not a clear explanation as to why the mid value of the original range is assigned as the lower bound of the new range. Please explain the reasoning behind this decision.

Guidehouse Response: If the facility indicated they would have continued using the fryer for 2-3 years or that the fryer was in good working condition, we assume the fryer would have still been installed and operating for several more years. We adjust the lower estimate of the EUL range to account for this, as the end of the useful life is therefore unlikely to be in the lower half of the originally-defined range.

3) Page 28, Conclusions – Guidehouse states that an assessment of the EUL for commercial fryers in different kitchen types was attempted but no quantitative results could be drawn. For future EUL research, SoCalGas recommends factoring in facility type differences in the EUL for a particular technology, as some cases may show significant lifecycle differences depending on facility type.

Guidehouse Response: We agree with this statement, and have been working with implementers (installing all different types of technologies) to better refine the data collection tools that are utilized upon equipment changeout.

Comment 4) Page 28, Conclusions – The conclusion of the report states that "there is a risk that new gas fryers … will have a longer lifetime than the previous generation … but Guidehouse believes that this risk is minimal given that the Energy Star standard … has not significantly changed for the last 10 years." SoCalGas suggests researching the lifecycle of current efficient equipment, as there may be significant lifecycle changes over time regardless of energy efficiency, or the Energy Star standard.

Guidehouse Response: This is a challenge with such durability research – it is not always possible to accurately estimate the ultimate lifespan of a new technology. By default, the passage of time is required to estimate lifespan under real world conditions. We think that by at least identifying the risks associated with our conclusions, that the reader can make an informed decision about implementing those conclusions.

SoCalGas would like to thank Guidehouse for the analysis of the gas fryer EUL. SoCalGas believes that an adequate and appropriate analysis was performed. The information provided from this research will prove useful for future EUL studies and workpaper development.