NATIONAL RENEWABLE ENERGY LABORATORY

Chapter 7: Refrigerator Recycling Evaluation Protocol

The Uniform Methods Project: Methods for Determining Energy Efficiency Savings for Specific Measures

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1 Measure Description

Refrigerator recycling programs are designed to save energy through the removal of old-but-operable refrigerators from service. By offering free pickup, providing incentives, and disseminating information about the operating cost of old refrigerators, these programs are designed to encourage consumers to:

- Discontinue the use of secondary[1] refrigerators
- Relinquish refrigerators previously used as primary units when they are replaced (rather than keeping the old refrigerator as a secondary unit)
- Prevent the continued use of old refrigerators in another household through a direct transfer (giving it away or selling it) or indirect transfer (resale on the used appliance market).

Commonly implemented by third-party contractors (who collect and decommission participating appliances), these programs generate energy savings through the retirement of inefficient appliances. The decommissioning process captures environmentally harmful refrigerants and foam and enables the recycling of the plastic, metal, and wiring components.

1 Secondary refrigerators are units not located in the kitchen.

2 Application Conditions of Protocol

These brief descriptions indicate the range of designs currently seen in recycling programs:

- Some recycle both primary and secondary refrigerators.
- Some accept only secondary refrigerators.
- Some impose restrictions on vintage eligibility.
- Some are offered in conjunction with point-of-sale rebates to encourage the purchase of ENERGY STAR-rated refrigerators.
- Some are offered as part of low-income, direct-install programs that install high-efficiency replacement units.[2]

The evaluation protocols described in this document, which pertain to all program variations listed, cover the energy savings from retiring operable-but-inefficient refrigerators. This protocol does not discuss the potential energy savings associated with the subsequent installation of a high-efficiency replacement refrigerator (which may occur as part of a separate retail products program).[3]

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[2] Low-income, direct-install programs target refrigerators that otherwise would have continued to operate and replace them with comparably sized, new, high-efficiency models. Therefore, the basis for estimating savings from these types of programs is different from the other program variations noted. This difference is discussed further in the *Savings Calculations* section of this chapter.

[3] As discussed under the section *Considering Resource Constraints* of the "Introduction" chapter to this UMP Report, small utilities (as defined under the U.S. Small Business Administration [SBA] regulations) may face additional constraints in undertaking this protocol. Therefore, alternative methodologies should be considered for such utilities.

3 Savings Calculations

The total gross energy savings[4] (kWh/year) achieved from recycling old-but-operable refrigerators is calculated using the following general algorithm:

Equation 1

$$GROSS\_kWh = N * EXISTING\_UEC * PART\_USE$$

Where:

GROSS_kWh	=	Annual electricity savings measured in kilowatt-hours (kWh)
N	=	The number of refrigerators recycled through the program
EXISTING_UEC	=	The average annual unit energy consumption of participating refrigerators
PART_USE	=	The portion of the year the average refrigerator would likely have operated if not recycled through the program

Due to the considerable potential for freeridership in appliance recycling programs in general, this protocol includes a discussion of net savings. For this protocol, the net adjustment accounts for current early replacement and recycling practice. The total net energy savings (kWh/year) is calculated as follows:

Equation 2

$$NET\_kWh = N * (NET\_FR\_SMI\_kWh - INDUCED\_kWh)$$

Where:

NET_FR_SMI_kWh	=	Average per-unit energy savings net of naturally occurring removal from grid and secondary market impacts
INDUCED_kWh	=	Average per-unit energy consumption caused by the program inducing participants to acquire refrigerators they would not have independent of program participation[5]

The recommended techniques for estimating each of these parameters are described below.

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4 The evaluation protocol methods focus on energy savings; they do not include other parameter assessments such as peak coincidence factor (demand savings), incremental cost, or measure life.

5 That is, the program caused customers to buy a new unit when they otherwise would not have. More information regarding induced replacement is included in this protocol's *Net Savings* section.

4 Gross Savings

This section provides instructions for determining the parameters required to estimate a refrigerator recycling program's total gross savings (GROSS_kWh).

The key parameters are:

- Measure Verification (N)
- Annual Energy Consumption (EXISTING_UEC)
- Part Use Factor (PART_USE).

4.1 Measure Verification (N)

The program administrator or the third-party implementation contractor should record the number of refrigerators recycled through a program. Ideally, the data for all participating refrigerators are compiled electronically in a database that tracks the following information (at a minimum):

- Age (in years, or year of manufacture)
- Size (in cubic feet)
- Configuration (top freezer, bottom freezer, side-by-side, or single door)
- Date the refrigerator was removed
- Complete customer contact information.

This protocol recommends that early in the evaluation process, the evaluators review the program databases to ensure they are being fully populated and contain sufficient information to inform subsequent evaluation activities.

Self-reported verification of program recycling records via a survey of randomly sampled participants has proven to be a reliable methodology. Survey efforts should include a sufficient sample of participants to meet the required level of statistical significance. When no requirements exist, this protocol recommends a sample that achieves, at minimum, 90% level of confidence with a 10% margin of error. Past evaluations have shown that participants typically have little difficulty confirming the number of units recycled and the approximate date the removal took place (Cadmus 2010).

4.2 Annual Energy Consumption (EXISTING_UEC)

To determine the average per-unit annual energy consumption, use a regression-based analysis that relies on either:

- Metering a sample of participating units or
- Using metered data collected as part of other recycling program evaluations that occurred within the previous five years (when evaluation resources do not support primary data collection).

Deemed savings, as determined through either of these approaches, may be used but need to be updated at least every three years to account for program maturation.

This protocol strongly recommends that evaluators conduct a metering study, if possible. As this method is the preferred evaluation approach, the remainder of this section outlines the best practices for (1) implementing a metering study and (2) using the results to estimate annual energy consumption and, subsequently, energy savings.

4.2.1 About In Situ Metering

Historically, recycling evaluations have primarily relied on unit energy consumption (UEC) estimates from the U.S. Department of Energy (DOE) testing protocols (DOE 2008).[6] However, recent evaluations indicate that DOE test conditions (for example, empty refrigeration and freezers cabinets, no door openings, and 90˚F test chamber) may not accurately reflect UECs for recycled appliances (ADM 2008, Cadmus 2010). As a result, evaluations have increasingly utilized *in situ* (meaning "in its original place") metering to assess energy consumption.

In situ metering is recommended for two reasons:

- It factors in environmental conditions and usage patterns within participating homes (for example, door openings, unit location, and exposure to weather), which are not explicitly accounted for in DOE testing.
- Most of the DOE-based UECs that are publicly available in industry databases were made at the time the appliance was manufactured, rather than when the unit was retired. Using testing data from the time of manufacture requires that assumptions be made about the degree of an appliance's degradation. *In situ* metering is conducted immediately prior to program participation (that is, at the time of the unit's retirement), so making a similar type of adjustment or assumption is unnecessary.

In summary, while the DOE testing protocols provide accurate insights into the relative efficiency of appliances (most commonly at their time of manufacture), *in situ* metering yields the most accurate estimate of energy consumption (and, therefore, savings) for old-but-operable appliances.

4.2.1.1 Key Factors for In Situ Metering

The following factors should be considered when implementing an *in situ* metering study:

- ***Sample Size.*** The recommended levels of statistical significance, which dictate the necessary sample size, are outlined in Chapter 11: *Sample Design*. It is recommended that evaluators assume a minimum coefficient of variation of 0.5 to ensure that a sufficient sample is available to compensate for attrition issues that routinely occur in field measurement.[7] For refrigerators, these attrition issues may include simple meter failure, relocation of the unit during metering, and atypical usage (for example, the refrigerator is prematurely emptied in preparation for program pickup). This protocol recommends that evaluators educate study participants (and provide written leave-

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[6] Evaluations have also used forms of billing analysis; however, the protocol does not recommend billing analysis or any other whole-house approach. The magnitude of expected savings—given total household energy consumption and changes in consumption unrelated to the program—could result in a less certain estimate than could be obtained from end-use specific approach.

[7] For a broader discussion of the coefficient of variation see the "Sample Design" chapter.

behind materials) about not relocating the refrigerator or otherwise using the unit in any manner inconsistent with historical usage.

- ***Stratification.*** The program theory assumes that the majority of recycled appliances would have been used as secondary units had they not been decommissioned through the program.[8] However, some units may continue to operate as a primary unit within the same home. To account correctly for differences in usage patterns between the usage type categories (for example, primary and secondary refrigerators), it is critical to stratify the metering sample to represent the different usage types.[9]

  For programs evaluated previously, information may be available about the proportion of refrigerators likely to have been used as primary versus secondary units. If so, that information can be leveraged to develop stratification quotas for the metering study.

  Once established, strict quotas should be enforced during the recruitment process, because participants who recycle secondary appliances are typically more willing to participate in a metering study than those who recycle primary appliances. Participants who are recycling their primary appliance are typically replacing them, and they are often unwilling to deal with the logistics related to rescheduling the delivery of their new unit.

  Additional stratification is not critical, due to the high degree of collinearity between refrigerator age, size, and configuration. However, when sufficient evaluation resources are available, targeting a sample of appliances with less-common characteristics can reduce collinearity and increase the final model's explanatory power.

- ***Duration.*** To capture a range of appliance usage patterns, meters need to be installed for a minimum of 10 to 14 days.[10] Collecting approximately two weeks' worth of energy-consumption data ensures that the metering period covers weekdays and weekends. Longer metering periods will provide a greater range of usage (and more data points), but the duration needs to be balanced with the customers' desire to have the refrigerator removed and recycled.

- ***Equipment.*** To capture information on compressor cycling, record the data in intervals of five minutes or less. If the meters' data capacity permits, shorter intervals (of one or two minutes) are preferable. When possible, meter the following parameters; however, if metering efforts are limited, prioritize the parameters in this order:
  - Current and/or power

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8 This includes several scenarios: The refrigerator may continue as a secondary appliance within the same home, be transitioned from a primary to secondary appliance within the same home, or become a secondary unit in another home.

9 This protocol recommends stratification by usage type even for programs that only accept secondary units as primary units are typically still recycled through these programs (via gaming or confusion about requirements).

10 The previously cited evaluations in California (ADM, April 2008 and Cadmus, February 2010) both collected metering data for a minimum of from 10 to 14 days.

- Internal refrigerator and/or freezer cabinet temperature
- Ambient temperature
- Frequency and duration of door openings.[11]

Not all of the aforementioned metered values are used to determine energy consumption. Some help identify potential problems in the metering process and, thus, increase the quality of the data. (For example, a comparison of ambient room temperature to internal cabinet temperature can be used to determine if the appliance was operational throughout the entire metering period.) This protocol recommends that evaluators perform similar diagnostics on all raw metering data before including an appliance in the final analysis dataset.

- ***Seasonality.*** Previous metering studies have shown that the energy consumption of secondary appliances in unconditioned spaces differs by season—especially in regions that experience extreme summer and/or winter weather.[12] As a result, metering needs to be conducted in waves on separate samples. By capturing a range of weather conditions using multiple metering waves (which include winter and summer peaks, as well as shoulder seasons), it is possible to annualize metering results more accurately. If it is not possible to meter appliances during multiple seasons, then annualize the metered data using existing refrigerator load shapes (utility-specific, when available) to avoid producing seasonally biased estimates of annual unit consumption.

- ***Recruitment.*** When arranging for metering, evaluators must contact participating customers before the appliance is removed. By working closely with the program implementers (who can provide daily lists of recently scheduled pickups), evaluators can contact those customers to determine their eligibility and solicit their participation in the metering study.

  This protocol recommends providing incentives to participants. Incentives aid in recruitment because they both provide recognition of the participants' cooperation and offset the added expense of continuing to operate their refrigerator during metering.

  Once participants are recruited, the evaluator and the implementer should collaborate in scheduling the participants' pickup after all of the metering equipment is removed.

- ***Installation and Removal.*** Evaluators can install and remove all metering equipment, or, to minimize costs, program implementers can perform these functions. However, when program implementers are involved in the metering process, the evaluator must

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[11] The previously cited evaluation (Cadmus, February 2010) employed the following metering equipment: HOBO U9-002 Light Sensor (recorded the frequency and duration of door openings), HOBO U12-012 External Data Logger (recorded the ambient temperature and humidity), HOBO U12-012 Internal Data Logger (recorded the cabinet temperature), HOBO CTV-A (recorded the current), and the Watts up? Pro ES Power Meter (recorded energy consumption).

[12] Forthcoming *Michigan Energy Efficiency Measure Database* memo by Cadmus regarding Consumers Energy and DTE Energy appliance recycling programs.

still independently conduct all sampling design and selection, recruitment, metering equipment programming, data extraction, and data analysis.

To ensure installations and removals are performed correctly, evaluators should train the implementers' field staff members and, ideally, accompany them on a sample of sites. If time and evaluation resources permit, evaluators should verify early in the first wave the proper installation of metering equipment at a small sample of participating homes Thus, any installation issues can be identified and corrected.

Because the metering process requires an additional trip to customer homes, evaluators need to compensate the implementers for their time. Consequently, the evaluators should contact implementers as early as possible to determine the viability of this approach and agree upon the appropriate compensation.

- ***Frequency.*** Because the characteristics of recycled refrigerators change as a program matures and greater market penetration is achieved, metering should be conducted approximately every three years. Savings estimates that rely exclusively on metering data older than three years reflect the current program year inaccurately. This is most commonly due to changes in the mix of recycled appliances manufactured before and after the establishment of appliance-related standards (including various state, regional, or federal standards) between program years. The main impact of these changes is a long-term downward effect on the savings associated with recycling programs.

4.2.2 About Regression Modeling

To estimate the annual UEC of the average recycled refrigerator, this protocol recommends that evaluators use a multivariate regression model(s) that relates observed energy consumption to refrigerator characteristics.

Evaluators should employ models that use daily or hourly observed energy consumption as the dependent variable. Independent variables should include key refrigerator characteristics or environmental factors determined to be statistically significant. This functional form allows the coefficient of each independent variable to indicate the relative influence of that variable (or appliance characteristic) on the observed energy consumption, holding all other variables constant. This approach allows evaluators to estimate the energy consumption of all participating appliances based on the set of characteristics maintained in the program's tracking database.

In estimating UEC, both time and cross-sectional effects must be accounted for. This can be done one of two ways:

- ***Use model that estimates simultaneously the impacts of longitudinal (time) and cross-sectional effects on energy consumption.*** This approach is recommended if the sample size is reasonably large *and* if units are observed across both summer and winter peak periods.

- ***Use a set of time-series models.*** If metering is done during only one or two seasons, use a refrigerator load shape from a secondary source to extrapolate the annual UEC for each metered refrigerator. Then apply a regression model using the entire metering sample to predict annualized consumption as a function of cross-sectional variables.

Once model parameters are estimated, the results may be used to estimate UEC for each refrigerator recycled through a program, based on each unit's unique set of characteristics. An example is provided later in this section.

The exact model specification (a set of appliance characteristics or independent variables) yielding the greatest explanatory power varies from study to study, based on the underlying metering data. Thus, this protocol does not mandate a certain specification be used. However, evaluators should consider—at a minimum—the following independent variables:

- Age (years) and corresponding vintage (compliance with relevant efficiency code)
- Size (in cubic feet)
- Configuration (top freezer, bottom freezer, side-by-side, or single door)
- Primary/secondary designation
- Conditioned/unconditioned space[13]
- Location (kitchen, garage, basement, porch, etc.)
- Weather (cooling degree days [CDD] and/or heating degree days [HDD]).

For each set of potential independent variables, evaluators should assess the variance inflation factors, adjusted R^2s, residual plots, and other measures of statistical significance and fit.

In the specification process, evaluators should also consider the following elements:

- Estimating model parameters by using an Ordinary/Generalized Least Squares method
- Transforming explanatory variables (logged and squared values, based on theoretical and empirical methods)
- Considering interaction terms (such as between refrigerators located in unconditioned space and CDD/HDD) when they are theoretically sound (that is, not simply to increase the adjusted R^2 or any other diagnostic metric)
- Balancing model parsimony with explanatory power. (It is very important not to over-specify the model(s). As the regression models are used to predict consumption for a wide variety of units, overly specified models can lose their predictive validity.)

[13] Primary/secondary and conditioned/unconditioned space variables may exhibit a strong collinearity. Consequently, do not include both in the final model.

The following sample regression model is based on data from 472 refrigerators metered and recycled through five utilities:

$$Existing\ UEC = 365.25 * [0.582 + 0.027 * (22.69\ years) + 1.055 * (63\%\ manufactured\ before\ 1990) + 0.067 * (18.92\ ft.^3) - 1.977 * (6\%\ single\ door\ units) + 1.071 * (25\%\ side - by - side) + 0.605 * (36\%\ primary\ usage) + 0.02 * (2.49\ unconditioned\ CDDs) - 0.045 * (1.47\ unconditioned\ HDDs)]$$

Once the characteristics of a specific appliance are determined, they should be substituted in the equation to estimate the UEC for that appliance. After the UEC is calculated for each participating unit, a program average UEC can be determined. Table 1 provides an example of this process, using average values for each independent variable from an example program.

Table 1: Example UEC Calculation Using Regression Model and Program Values

Independent Variable	Estimate Coefficient (Daily kWh)	Program Values (Average/Proportion)
Intercept	0.582	-
Appliance Age (years)	0.027	22.69
Dummy: Manufactured Pre-1990	1.055	0.63
Appliance Size (square feet)	0.067	18.92
Dummy: Single-Door Configuration	-1.977	0.06
Dummy: Side-by-Side Configuration	1.071	0.25
Dummy: Primary Usage Type (in absence of the program)	0.6054	0.36
Interaction: Located in Unconditioned Space x CDDs	0.020	2.49
Interaction: Located in Unconditioned Space x HDDs	-0.045	1.47
Estimated UEC (kWh/Year)		**1,240**

4.2.3 Using Secondary Data

When evaluation resources do not support *in situ* metering, evaluators should leverage a model developed through the most appropriate *in situ* metering-based evaluation undertaken for another utility. The most appropriate study will be one that is comparable to the program being evaluated in terms of the following factors:

- Age of the study (recent is most desirable)
- Similar average appliance characteristics (comparable sizes, configurations, etc.)
- Similar geographical location (due to differences in climate)
- Similar customer demographics (due to differences in usage patterns).

Use the aggregated UEC model presented in Table 1 when (1) *in situ* metering is not an option *and* (2) a recently developed model from a single comparable program cannot be identified.

4.3 Part-Use Factor (PART_USE)

"Part-use" is an appliance recycling-specific adjustment factor used to convert the UEC (determined through the methods detailed above) into an average per-unit gross savings value. The UEC itself is not equal to the gross savings value, because:

- The UEC model yields an estimate of annual consumption
- Not all recycled refrigerators would have operated year-round had they not been decommissioned through the program.

Table 2 provides a summary of the three part-use categories, each with its own part-use factor. The part-use factors for refrigerators that would have run full-time (1.0) and those that would have not run at all (0.0) are consistent across evaluations. The part-use factor for refrigerators that would have been used for a portion of the year varies by program (and is between 0.0 and 1.0). For example, a refrigerator estimated to operate a total of three months over the course of a year (most commonly to provide additional storage capacity during the holidays) would have a part-use factor of 0.25.

Table 2: Part-Use Factors by Category

Part-Use Category	Part-Use Factor
Likely to not operate at all in absence of the program	0
Likely to operate part-time in absence of the program	0 to 1
Likely to operate year-round in absence of the program	1

Using participant surveys, evaluators should determine the number of recycled units in each part-use category, as well as the portion of the year that the refrigerators that *would have been used part-time* were likely to have been operated. The protocol recommends this assessment be handled through the following multi-step process:

1. ***Ask participants where the refrigerator was located for most of the year prior to being recycled.*** By asking about the refrigerator's long-term location, evaluators can obtain more reliable information about the unit's usage type and can avoid using terms that often confuse participants (such as primary and secondary), especially when replacement occurs. It is recommended that evaluators designate all refrigerators previously located in a kitchen as primary units and all other locations as secondary.

   Note that it is important not to ask about the refrigerator's location when it was collected by the program implementer, as many units are relocated to accommodate the arrival of a replacement appliance or to facilitate program pickup.

2. ***Ask those participants who indicated recycling a secondary refrigerator whether the refrigerator was unplugged, operated year-round, or operated for a portion of the preceding year.*** (Evaluators can assume all primary units are operated year-round.)

3. ***Ask those participants who indicated that their secondary refrigerator was operated for only a portion of the preceding year to estimate the total number of months during that time the refrigerator was plugged in.*** Then divide the average number of months

specified by this subset of participants by 12 to calculate the part-use factor for all refrigerators operated for only a portion of the year.

These three steps enable evaluators to obtain important and specific information about how a refrigerator was used before it was recycled. The example program provided in Table 3 shows that:

- The participant survey determined that 93% of recycled refrigerators were operated year-round either as primary or secondary units. (Again, the part-use factor associated with these refrigerators is 1.0.)
- Four percent of refrigerators were not used at all in the year before being recycled. The part-use factor associated with this portion of the program population is 0.0, and no energy savings are generated by the refrigerator's removal and eventual decommissioning.
- The remainder (3%) was operational for a portion of the year. Specifically, the survey determined that part-time refrigerators were operated for an average of three months a year (indicating a part-use factor of 0.25).

Using this information, evaluators should calculate the overall part-use factors for secondary units only, as well as for all recycled units. These factors are derived by applying a weighted average of the adjusted part-use per-unit energy savings for each part-use category. This calculation uses the UEC determined through the methods described in the *About Regression Modeling* section. In this example, the program's secondary-only part-use factor is 0.88, while the overall part-use factor is 0.93.

Table 3: Example Calculation of Historical Part-Use Factors

Usage Type and Part-Use Category	Percent of Recycled Units	Part-Use Factor	Per-Unit Energy Savings (kWh/Yr)
Secondary Units Only			
Not in Use	6%	0.00	-
Used Part-Time	8%	0.25	310
Used Full-Time	86%	1.00	1,240
Weighted Average	**100.0%**	**0.88**	**1,091**
All Units (Primary and Secondary)			
Not in Use	4%	0.00	-
Used Part-Time	3%	0.25	310
Used Full-Time	93%	1.00	1,240
Weighted Average	**100.0%**	**0.93**	**1,163**

Next, evaluators should combine these historically observed part-use factors with participants' self-reported action had the program *not* been available. (That is, the participants' report as to whether they would they have kept or discarded their refrigerator.)[14]

[14] Since the future usage type of discarded refrigerators is unknown, evaluators should apply the weighted part-use average of all units (0.93) for all refrigerators that would have been discarded independent of the program. This

The example provided in Table 4 demonstrates how a program's part-use factor is determined using a weighted average of historically observed part-use factors and participants' likely action in the absence of the program.[15] Here, the result is a part-use value of 0.91, based on the expected future use of the refrigerators had they not been recycled.

Table 4: Example Calculation of Prospective Program Part-Use

Use Prior to Recycling	Likely Use Independent of Recycling	Part-Use Factor	Percent of Participants
Primary	Kept (as primary unit)	1.0	15%
	Kept (as secondary unit)	0.88	25%
	Discarded	0.93	15%
Secondary	Kept	0.88	30%
	Discarded	0.93	15%
Overall	***All***	***0.91***	***100%***

Applying the determined prospective part-use factor (PART_USE) of 0.91 to the determined annual energy consumption (EXISTING_UEC) of 1,240 kWh/year yields the program's average per-unit gross savings. In this case, the gross savings is 1,128 kWh/year.

Recent evaluations of appliance recycling programs have determined that part-use factors typically range from 0.85 to 0.95 (Navigant 2010). Newer appliance recycling programs have exhibited a part-use factor at the lower end of this range. This is attributed to that fact that many unused or partially used appliances sat idle before the program launch simply because participants lacked the means to discard them. (The recycling program then provided the means.) In addition, the newer programs tend to focus on collecting secondary units (which are subject to part-use), while mature programs tend to focus on avoided retention (replacing primary appliances). As a result, part-use factors tend to increase over time.

The part-use factor should be reassessed annually for newer programs, because it may change more rapidly during the early stages of a program's life cycle. After a program has been in operation for at least three years, it is sufficient to conduct a part-use assessment every other year.

4.4 Refrigerator Replacement

In most cases, the per-unit gross energy savings attributable to the program is equal to the energy consumption of the recycled appliance (rather than being equal to the difference between the consumption of the participating appliance and its replacement, when applicable). This is because the energy savings generated by the program are not limited to the change within the participant's home, but rather to the total change in energy consumption at the grid level.

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approach acknowledges that discarded appliances might be used as primary or secondary units in the would-be recipient's home.

15 Evaluators should not calculate part-use using participant's estimates of future use had the program not been available. Historical estimates based on actual usage rates are more accurate, especially because it is possible participants will underestimate future usage (believing they will only operate it part of the year, despite the fact the majority of refrigerators operate continuously once plugged in).

This concept is best explained with an example. Suppose a customer decides to purchase a new refrigerator to replace an existing one. When the customer mentions this to a neighbor, the neighbor asks for that existing refrigerator to use as a secondary unit. The customer agrees to give the old appliance to the neighbor; however, before this transfer is made, the customer learns about a utility-sponsored appliance recycling program. The customer decides to participate in the program, because the incentive helps offsets the cost of the new refrigerator. As a result of program intervention, the customer's appliance is permanently removed from operation in the utility's service territory.

From the utility's perspective, the difference in grid-level energy consumption—and the corresponding increase in program savings—are equal to the consumption of the recycled appliance *and not* to the difference between the energy consumption of the participating appliance and its replacement. In this example, it is important to note that the participant planned to replace the appliance.

In general, the purchase of new refrigerators is part of the naturally occurring appliance life cycle, typically independent of the program[16] and tantamount to refrigerator load growth. It is not the purpose of the program to prevent these inevitable purchases, but rather to minimize the grid-level refrigerator load growth by limiting the number of existing appliances that continue to operate once they are replaced.

However, when a recycling program induces replacement (that is, the participant would ***not*** have purchased the new refrigerator in absence of the recycling program), evaluators must account for replacement. This issue is addressed in the following *Net Savings* section, which also discusses recycling program's impact on the secondary market and how evaluators should account for these effects. This protocol focuses on the actions of would-be recipients of refrigerators recycled through the program (that otherwise would have been transferred to a new user) when the recycled unit is not available.

Appliances that, independent of the program, would have been discarded in a way leading to destruction (such as being taken to a landfill)—rather than being transferred to a new user—are captured by the evaluation's net-to-gross (NTG) ratio. Thus, no net savings are generated by the program. This is a separate issue from estimating gross energy savings and is also discussed in the following *Net Savings* section in more detail.

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16 With the exception of induced replacement, which is addressed in *Net Savings*.

5 Net Savings

This section provides instructions for determining the additional parameters required to estimate a refrigerator recycling program's net savings (NET_kWh). In the case of refrigerator recycling, net savings are only generated when the recycled appliance would have continued to operate absent program intervention (either within the participating customer's home or at the home of another utility customer).

The key additional parameters detailed in this section are:

- Freeridership and Secondary Market Impacts (NET_FR_SMI_kWh)
- Induced Replacement (INDUCED_kWh).

5.1 Freeridership and Secondary Market Impacts (NET_FR_SMI_kWh)

To estimate freeridership and secondary market impacts, this protocol recommends that evaluators use a combination of the responses of surveyed participants, surveyed nonparticipants, and (if possible) secondary market research. These data are used together to populate a decision tree of all possible savings scenarios. A weighted average of these scenarios is then taken to calculate the savings that can be credited to the program after accounting for either freeridership or the program's interaction with the secondary market. This decision tree is populated based on what the participating household would have done outside the program *and*, if the unit would have been transferred to another household, whether the would-be acquirer of that refrigerator finds an alternate unit instead.

In general, independent of program intervention, participating refrigerators would have been subject to one of the following scenarios:

1. The refrigerator would have been kept by the household.
2. The refrigerator would have been discarded by a method that transfers it to another customer for continued use.
3. The refrigerator would have been discarded by a method leading to its removal from service.

These scenarios encompass what has often been referred to as "freeridership" (the proportion of units would have been taken off the grid absent the program). The quantification of freeridership is detailed in Section 5.1.1*, Freeridership*.

In the event that the unit would have been transferred to another household, the question then becomes what purchasing decisions are made by the would-be acquirers of participating units now that these units are unavailable. These would-be acquirers could:

1. Not purchase/acquire another unit
2. Purchase/acquire another used unit.

Adjustments to savings based on these factors are referred to as the program's secondary market impacts. The quantification of this impact is detailed in Section 5.1.2, *Secondary Market Impacts*.

5.1.1 Freeridership

The first step is to estimate the distribution of participating units likely to have been kept or discarded absent the program. Further, there are two possible scenarios for discarded units so, in total, there are three possible scenarios independent of program intervention:

1. Unit is discarded and transferred to another household
2. Unit is discarded and destroyed
3. Unit is kept in the home.

As participants often do not have full knowledge of the available options for and potential barriers to disposing refrigerators (Scenarios 1 and 2), this document recommends using nonparticipant survey data to mitigate potential self-reporting errors. The proportion of units that would have been kept in the home (Scenario 3) can be estimated exclusively through the participant survey, as participants can reliably provide this information.

Nonparticipant surveys provide information from other utility customers regarding how they actually discarded their refrigerator independent of the program. Evaluators can also use this information to estimate the proportion of discarded units that are transferred (Scenario 1) versus destroyed (Scenario 2).

Specifically, evaluators should calculate the distribution of the ratio of likely discard scenarios as a weighted average from both participants and nonparticipants (when nonparticipant surveys are possible). The averaging of participant and nonparticipant values mitigates potential biases in the responses of each group.[17] As the true population of nonparticipants is unknown, the distribution should be weighted using the inverse of the variance of participant and nonparticipant freeridership ratios.[18] This method of weighting gives greater weight to values that are more precise or less variable. As demonstrated in Table 5,[19] this approach results in the evaluation's estimation of the proportion of participating appliances that would have been permanently destroyed (Scenario 1), transferred to another user (Scenario 2), or kept (Scenario 3).

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17 Participant responses may be biased due to not fully understanding barriers to various disposal options. Nonparticipant decisions may not be representative of what participants would do in the absence of the program due to participants self-selecting into the program (as opposed to being randomly enrolled).

18 Inverse variance weights involve weighting each estimate by the inverse of its squared standard error ($1/SE^2$). This technique is common in the meta-analysis literature and is used to place greater weight on more reliable estimates.

19 More detail on how this information is utilized to determine net savings can be found in Section 6, *Summary Diagram*.

Table 5: Determination of Discard and Keep Distribution

Discard/ Keep	Proportion of Participant Sample	Sample	Discard Scenario	N	SE	Weight	Proportion of Discards	Overall Proportion
Discard	70%	Participant	Transfer	70	0.05	0.60	80%	
			Destroy				20%	
		Nonparticipant	Transfer	70	0.06	0.40	60%	
			Destroy				40%	
		Weighted Average	Transfer				72%	50%
			Destroy				28%	20%
Kept	30%							30%

5.1.1.1 Participant Self-Reported Actions

To determine the percentage of participants in each of the three scenarios, evaluators should begin by asking surveyed participants about the likely fate of their recycled appliance had it not been decommissioned through the utility program. Responses provided by participants can be categorized as follows:

- Kept the refrigerator
- Sold the refrigerator to a private party (either an acquaintance or through a posted advertisement)
- Sold or gave the refrigerator to a used-appliance dealer
- Gave the refrigerator to a private party, such as a friend or neighbor
- Gave the refrigerator to a charity organization, such as Goodwill Industries or a church
- Had the refrigerator removed by the dealer from whom the new or replacement refrigerator was obtained
- Hauled the refrigerator to a landfill or recycling center
- Hired someone else to haul the refrigerator away for junking, dumping, or recycling.

To ensure the most reliable responses possible and to mitigate socially desirable response bias, evaluators should ask some respondents additional questions. For example, participants may say they would have sold their unit to a used appliance dealer. However, if the evaluation's market research revealed used appliance dealers were unlikely to purchase it (due to its age or condition), then participants should be asked what they would have likely done *had they been unable to sell the unit to a dealer*. Evaluators should then use the response to this question in assessing freeridership.

If market research determines local waste transfer stations charge a fee for dropping off refrigerators, inform participants about the fee if they initially specify this as their option and then ask them to confirm what they would have done in the absence of the program. Again, evaluators should use this response to assess freeridership.

Use this iterative approach with great care. It is critical that evaluators find the appropriate balance between increasing the plausibility of participants' stated action (by offering context that might have impacted their decision) while not upsetting participants by appearing to invalidate their initial response.

Next evaluators should assess whether each participant's final response indicates freeridership.

- Some final responses clearly indicate freeridership, such as: "I would have taken it to the landfill or recycling center myself."
- Other responses clearly indicate no freeridership, as when the refrigerator would have remained active within the participating home ("I would have kept it and continued to use it") or used elsewhere within the utility's service territory ("I would have given it to a family member, neighbor, or friend to use").

5.1.2 Secondary Market Impacts

If it is determined that the participant would have directly or indirectly (through a market actor) transferred the unit to another customer on the grid, the next question addresses what that potential acquirer did because that unit was unavailable. There are three possibilities:

A. ***None of the would-be acquirers would find another unit.*** That is, program participation would result in a one-for-one reduction in the total number of refrigerators operating on the grid. In this case, the total energy consumption of avoided transfers (participating appliances that otherwise would have been used by another customer) should be credited as savings to the program. This position is consistent with the theory that participating appliances are essentially convenience goods for would-be acquirers. (That is, the potential acquirer would have accepted the refrigerator had it been readily available, but because the refrigerator was not a necessity, and the potential acquirer would not seek out an alternate unit.)

B. ***All of the would-be acquirers would find another unit.*** Thus, program participation has no effect on the total number of refrigerators operating on the grid. This position is consistent with the notion that participating appliances are necessities and that customers will always seek alternative units when participating appliances are unavailable.

C. ***Some of would-be acquirers would find another unit, while others would not.*** This possibility reflects the awareness that some acquirers were in the market for a refrigerator and would acquire another unit, while others were not (and would only have taken the unit opportunistically).

It is difficult to answer this question with certainty, absent utility-specific information regarding the change in the total number of refrigerators (overall and used appliances specifically) that were active before and after program implementation. In some cases, evaluators have conducted in-depth market research to estimate both the program's impact on the secondary market *and* the appropriate attribution of savings for this scenario. Although these studies are imperfect, they can provide utility-specific information related to the program's net energy impact. Where feasible, evaluators and utilities should design and implement such an approach. Unfortunately, this type of research tends to be cost-prohibitive, or the necessary data may simply be unavailable.

Because the data to inform such a top-down market-based approach may be unavailable, evaluators have employed a bottom-up approach that centers on identifying and surveying recent acquirers of non-program used appliances and asking these acquirers what they would have done had the specific used appliance they acquired not been available. While this approach results in quantitative data to support evaluation efforts, it is uncertain if:

- The used appliances these customers acquired are in fact comparable in age and condition to those recycled through the program
- These customers can reliably respond to the hypothetical question.

Further, any sample composed entirely of customers who recently acquired a used appliance seems inherently likely to produce a result that aligns with Possibility B, presented above.

As a result of these difficulties and budget limitations, this protocol recommends Possibility C when primary research cannot be undertaken. Specifically, evaluators should assume that half (0.5, the midpoint of possibilities A and B) of the would-be acquirers of avoided transfers found an alternate unit.

Once the proportion of would-be acquirers who are assumed to find alternate unit is determined, the next question is whether the alternate unit was likely to be another used appliance (similar to those recycled through the program) or, with fewer used appliances presumably available in the market due to program activity, would the customer acquire a new standard-efficiency unit instead.[20] For the reasons previously discussed, it is difficult to estimate this distribution definitively. Thus, this protocol recommends a midpoint approach when primary research is unavailable: evaluators should assume half (0.5) of the would-be acquirers of program units would find a similar, used appliance and half (0.5) would acquire a new, standard-efficiency unit.[21]

Figure 1 details the methodology for assessing the program's impact on the secondary market and the application of the recommended midpoint assumptions when primary data are unavailable. As evident in the figure, accounting for market effects results in three savings scenarios: full savings (i.e., per-unit gross savings), no savings, and partial savings (i.e., the

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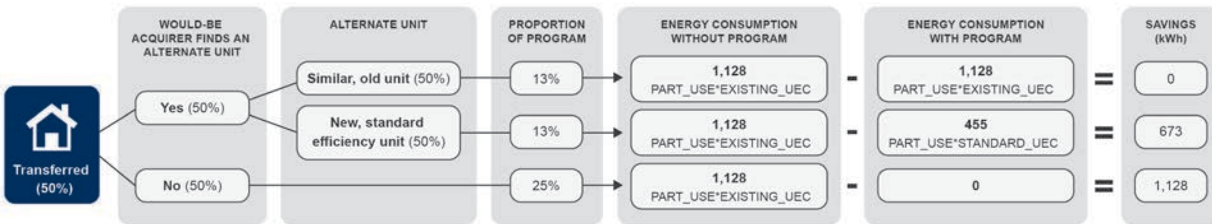
[20] It is also possible the would-be acquirer of a program unit would select a new ENERGY STAR unit as an alternate. However, we recommend evaluators assume any such used appliance supply-restricted upgrades be limited to new, standard-efficiency units because (1) it seems most likely a customer in the market for a used appliance would upgrade to the new lowest price point and (2) excluding ENERGY STAR units avoids potential double counting between programs when utilities offer concurrent retail rebates.

[21] Evaluators should determine the energy consumption of a new, standard-efficiency appliance using the ENERGY STAR website. Specifically, evaluators should average the reported energy consumption of new, standard-efficiency appliances of comparable size and similar configuration to the program units.

difference between the energy consumption of the program unit and the new, standard-efficiency appliance acquired instead).[22]

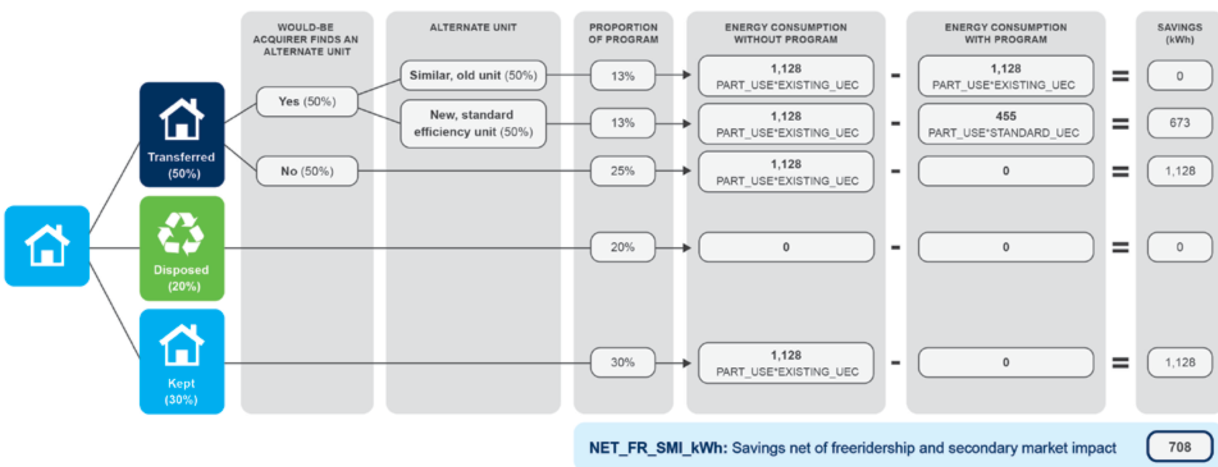
Figure 1: Secondary Market Impacts



5.1.3 Integration of Freeridership and Secondary Market Impacts

Once the parameters of the freeridership and secondary market impacts are estimated, a decision tree can be used to calculate the average per-unit program savings net of their combined effect. Figure 2 shows how these values are integrated into a combined estimate (NET_FR_SMI_kWh, here shown on a per-unit basis).

Figure 2: Savings Net of Freeridership and Secondary Market Impacts



As shown above, evaluators should estimate per-unit NET_FR_SMI_kWh by calculating the proportion of the total participating units associated with each possible combination of freeridership and secondary market scenarios and its associated energy savings.

5.2 Induced Replacement (INDUCED_kWh)

Evaluators must account for replacement units *only* when a recycling program induces replacement (that is, when the participant would *not* have purchased the replacement refrigerator in the absence of the recycling program). As previously noted, the purchase of a refrigerator in conjunction with program participation does not necessarily indicate induced replacement. (The refrigerator market is continuously replacing older refrigerators with new units, independent of

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22 More detail on how this information is used to determine net savings can be found in Section 6, *Summary Diagram*.

any programmatic effects.) However, if a customer would have not purchased the replacement unit (put another appliance on the grid) in absence of the program, the net program savings should reflect this fact. This is, in effect, akin to negative spillover and should be used to adjust net program savings downward.

Estimating the proportion of households induced to replace their appliance can be done through participant surveys. As an example, participants could be asked, "Would you have purchased your replacement refrigerator if the recycling program had not been offered?"

Because an incentive ranging from $35 to $50 is unlikely to be sufficient motivation for purchasing an otherwise-unplanned replacement unit (which can cost $500 to $2,000), it is critical that evaluators include a follow-up question. That question should confirm the participants' assertions that the program alone caused them to replace their refrigerator.

For example, participants could be asked, "Let me be sure I understand correctly. Are you saying that you chose to purchase a new appliance because of the appliance recycling program, or are you saying that you would have purchased the new refrigerator regardless of the program?"

When assessing participant survey responses to calculate induced replacement, evaluators should consider the appliance recycled through the program, as well as the participant's stated intentions in the absence of the program. For example, when customers indicated they would have discarded their primary refrigerator independent of the program, it is not possible that the replacement was induced (because it is extremely unlikely the participant would live without a primary refrigerator). Induced replacement is a viable response for all other usage types and stated intention combinations.

As one might expect, previous evaluations have shown the number of induced replacements to be considerably smaller than the number of naturally occurring replacements unrelated to the program.[23] Once the number of induced replacements is determined, this information is combined with the energy consumption replacement appliance, as shown in Figure 3, to determine the total energy consumption induced by the program (on a per-unit basis).[24,25] As

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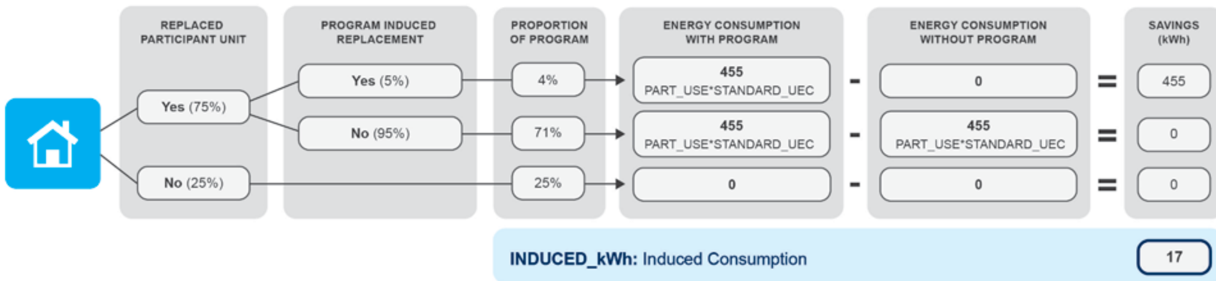
23 http://www.pacificorp.com/content/dam/pacificorp/doc/Energy_Sources/Demand_Side_Management/WA_2011_SYLR_Final_Report.pdf

24 Unlike the secondary market effects analysis, it is possible to ask participants who say their replacement was induced by the program during the survey whether the replacement unit was a comparable used appliance, a new standard-efficiency unit, or a new ENERGY STAR unit. For the sake of simplicity assumes all induced replacements were new, standard-efficiency units because (1) it seems likely customers would seek to upgrade their appliances when replacing (that is, they would be less likely to replace with another used units); and (2) similar to the secondary market effects analysis, excluding ENERGY STAR units avoids potential double counting between programs when utilities offer concurrent retail rebates. However, evaluators should use this more detailed information when it is available and when concerns about double counting are either not applicable or can be addressed through the survey.

25 Evaluators should determine the energy consumption of a new, standard-efficiency appliance using the ENERGY STAR website. Specifically, average the reported energy consumption of new, standard-efficiency appliances with units that are comparably sized and have configurations similar to the program units.

shown in the example below, this analysis results in an increase of 17 kWh per unit associated with induced replacement.

Figure 3: Induced Replacement



5.3 Spillover

This protocol does not recommend quantifying and applying participant spillover to adjust net savings for the following reasons:

- Unlike a CFL program, the opportunities for "like" spillover (the most common and defensible form of spillover for most downstream DSM programs) are limited in a recycling program because the number of refrigerators available for recycling in a typical home is limited.
- Unlike a whole-house audit program, recycling programs typically do not provide comprehensive energy education that would identify other efficiency opportunities within the home and generate "unlike" spillover.
- Quantifying spillover accurately is challenging and, despite well-designed surveys, uncertainty often exists regarding the attribution of subsequent efficiency improvements to participation in the recycling program.

However, as a result of the ease of participation and high levels of participant satisfaction, appliance recycling programs may encourage utility customers to enroll in other available residential programs. While this is a positive attribute of recycling programs within a residential portfolio, all resulting savings are captured by other program evaluations.

5.4 Data Sources

After determining a program's gross energy savings, the net savings are determined by applying a NTG adjustment using the follow data sources[26]:

- ***Participant Surveys***. Surveys with a random sample of participants offer self-report estimates regarding whether participating refrigerators would have been kept or discarded independent of the program.[27] When participants indicate the recycled

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[26] When it is cost-prohibitive to survey nonparticipants and interview market actors, calculate freeridership using participant surveys and secondary data from a comparable set of market actors.

[27] As noted previously, the number of participant surveys should be sufficient to meet the required level of statistical significance. A minimum of 90% confidence with 10% precision is suggested.

refrigerator would have been discarded, ask for further details as to their likely method of disposal in the absence of the program. For example, ask whether the appliance would have been given to a neighbor, taken to recycling center, or sold to used-appliance dealer.

- ***Nonparticipant*[28] *Surveys***. To mitigate potential response bias,[29] this protocol recommends using nonparticipant surveys to obtain information for estimating NTG. Information about how nonparticipants actually discarded their operable refrigerators outside of the program can reveal and mitigate potential response bias from participants. (Participants may overstate the frequency with which they would have recycled their old-but-operable refrigerator, because they respond with what they perceive as being socially acceptable answers.) Nonparticipants, however, can only provide information about how units were actually discarded.[30] Because nonparticipant surveys require greater evaluation resources, it is acceptable to use smaller sample sizes.[31] [32]
- ***Market Research***. Some participant and nonparticipant responses require additional information for determining definitively whether the old-but-operable refrigerator would have been kept in use absent the program. Responses requiring follow-up include:
    - "I would have sold it to a used appliance dealer"
    - "I would have had the dealer who delivered my new refrigerator take the old refrigerator."

  To inform a more robust NTG analysis, conduct market research by interviewing senior management from new appliance dealers and used appliance dealers (both local chains and big-box retailers). Ask about the viability of recycled refrigerators being resold on the used market had they not been decommissioned through the program. For example, do market actors resell none, some, or all picked-up refrigerators? If only some are resold, what are characteristics (for example, age, condition, features) that determine when a refrigerator is for resale. Information gained through this research (which should be conducted before the participant surveys) can be used to assess the reasonableness of participants' self-reported hypothetical actions independent of the program. This information can also be used to prompt participants to offer alternative hypothetical actions.[33]

A detailed explanation of how to estimate NTG by aggregating information from these sources is

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28 "Nonparticipants" are defined as utility customers who disposed of an operable refrigerator outside of the utility program while the program was being offered.

29 See the "Sample Design" chapter for a broader discussion of sources of bias.

30 Information regarding the likelihood that the recycled refrigerator would have been retained independent of program intervention can be obtained reliably through the participant surveys.

31 The cost of identifying nonparticipants can be minimized by adding the nonparticipant NTG module to concurrent participant surveys for other utility program evaluations.

32 For a general discussion of issues related to conducting surveys, see the "Survey Design" chapter.

33 More detail is provided in Section 5.3 *Freeridership (FR_RATIO)*.

provided later in this section. Also, as previous recycling evaluations have found little evidence of program-induced spillover,[34] this protocol does not require that spillover be addressed quantitatively.[35] As a result, estimates of NTG need only to account for freeridership and induced replacement.

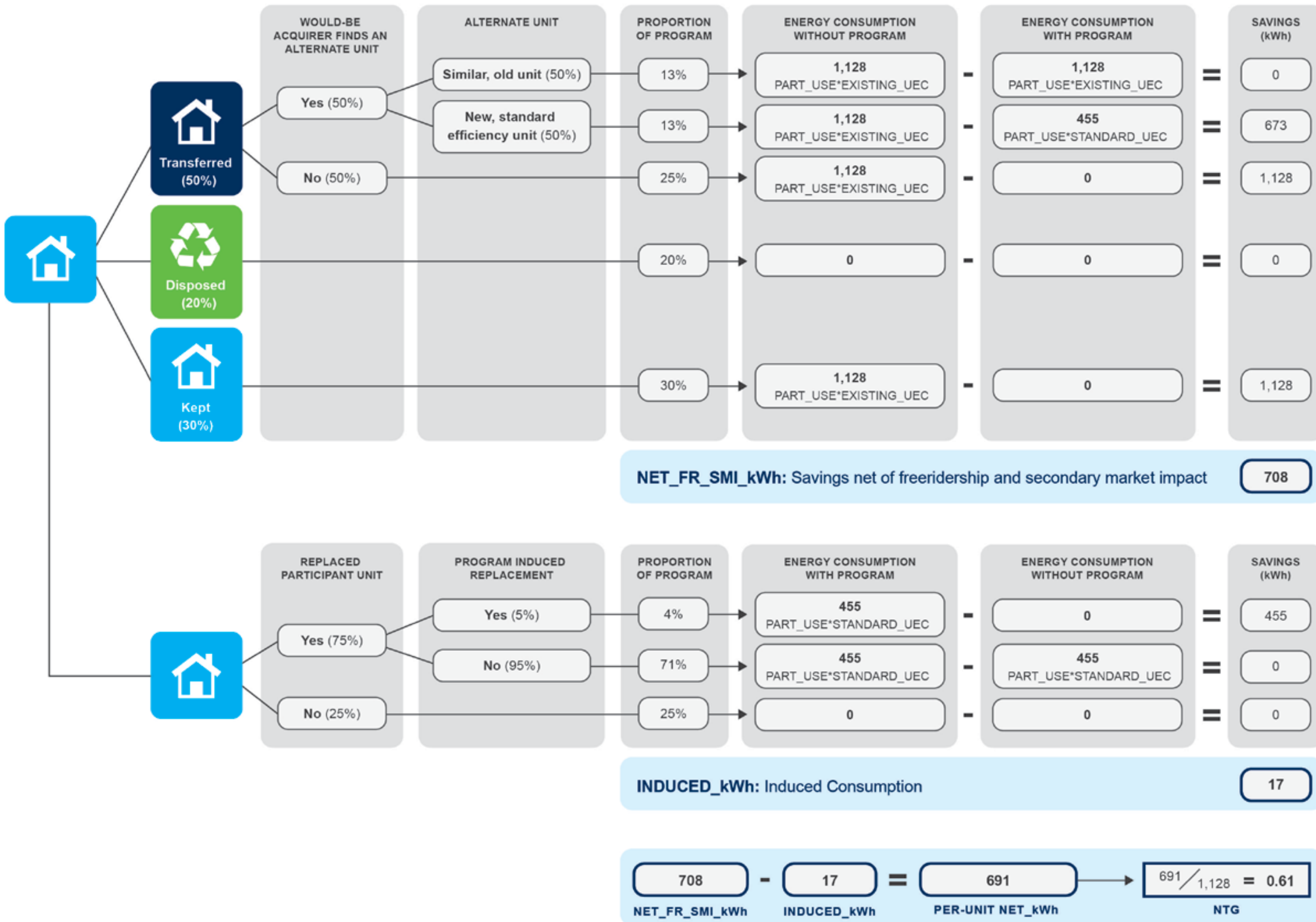
34 Spillover will be discussed in the Net-to-Gross protocol developed in Phase 2 of the Uniform Methods Project. CHECK AT END OF PROCESS

35 This issue is discussed further in Cadmus' forthcoming evaluation of PacifiCorp's Appliance Recycling Program in Washington.

6 Summary Diagram

Figure 4 summarizes the net savings methodology outlined in this protocol.

Figure 4: Refrigerator Recycling Net Savings Evaluation Protocol: Summary Diagram



7 Other Evaluation Issues

7.1 Remaining Useful Life

It is difficult to determine the number of years that a recycled refrigerator would have continued to operate absent the program and, therefore, the longevity of the savings generated by recycling old-but-operable refrigerators through the program. Participant self-reports are speculative and cannot account for unexpected appliance failure. Also, the standard evaluation measurements of remaining useful life (RUL) are not applicable, as most participating refrigerators are already past their effective useful life (EUL) estimates.

More primary research is needed on this topic to identify a best practice. In the interim and in lieu of a formal recommendation, this protocol offers two examples of estimation methods.

- RUL can be estimated as a function of a utility's new refrigerator EUL, using the following formula[36]: RUL = EUL/3
- RUL can be estimated using survival analysis (when appropriate data are available).[37]

7.2 Freezers

Although this protocol focuses on refrigerators, most utility appliance recycling programs also decommission stand-alone freezers. While differences exist between the evaluation approach for each appliance type (for example, all stand-alone freezers are secondary units, while refrigerators may be primary or secondary units), this protocol can also be used to evaluate the savings for freezers.

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36 This formula was obtained from the *Database for Energy Efficient Resources* (http://www.energy.ca.gov/deer/).

37 In an evaluation of the NV Energy appliance recycling program, ADM Associates used survival analysis using secondary data using data from the 2009 California RASS. This involved estimating hazard rates for refrigerators based on the observed destruction of appliances at various ages. Once the hazard rate function was estimated, a table of expected RULs at each age was calculated. Where feasible, this approach should be followed using data specific to the given utility service area.

8 Resources

10 CFR 430.23(A1). (2008). www.gpo.gov/fdsys/pkg/CFR-2011-title10-vol3/pdf/CFR-2011-title10-vol3-part430-subpartB-appA.pdf.

ADM Associates, Inc. (April 2008). Athens Research, Hiner & Partners and Innovologie LLC. *Evaluation Study of the 2004-05 Statewide Residential Appliance Recycling Program*. www.calmac.org/publications/EM&V_Study_for_2004-2005_Statewide_RARP_-_Final_Report.pdf.

Cadmus Group, Inc. (February 8, 2010). *Residential Retrofit High Impact Measure Evaluation Report*. www.calmac.org/publications/FinalResidentialRetroEvaluationReport_11.pdf.

Navigant Consulting. (December 21, 2010). *Energy Efficiency/Demand Response Plan: Plan Year 2 (6/1/2009-5/31/2010)—Evaluation Report: Residential Appliance Recycling*. www.ilsag.org/yahoo_site_admin/assets/docs/ComEd_Appliance_Recycling_PY2_Evaluation_Report_2010-12-21_Final.12113446.pdf.