



MEMORANDUM

To: Massachusetts Program Administrators and Energy Efficiency Advisory Council Consultants

From: Lisa Wilson-Wright and Katherine Weber, NMR

Date: March 27, 2018

Re: RLPNC 18-1 Appliance Recycling Database Review and Savings Update

The Massachusetts Program Administrators (PAs) and the Energy Efficiency Advisory Council Consultants (EEAC Consultants) currently sponsor a refrigerator and freezer recycling program (the Program) through the Residential Consumer Products Core Initiative. Marketed under the Mass Save® umbrella, the program collects unwanted refrigerators and freezers and pays an incentive of \$50 (usually) or \$100 (during special promotions) to customers who surrender the appliances to the program. In 2017, the program paid out 18,300 rebates. Of these 18,300 rebates, 15,637 were for recycled refrigerators and 2,663 were for recycled freezers. [Appendix A](#) includes a description of the dataset and units recycled through the program.

The last impact, process, and secondary market study performed on this program was completed in June 2011.¹ At that time Jaco served as program implementer (Jaco has since gone out business, creating a program hiatus in 2016), and the program had only been in operation since 2009 (for National Grid) and 2010 (for all other PAs). The PAs, EEAC, and NMR are currently finalizing a Stage 3 Plan for an impact and process evaluation of the Program.

Although the overall study scope is not yet final, the PAs and EEAC asked NMR to proceed with Task 1 of the proposed study. This memo presents the results of that task, which used program tracking data, information from a recent literature review, and savings algorithms recommended by the Uniform Methods Protocol (UMP) to update unit energy consumption (UEC) and per-unit

¹ NMR conducted the research, resulting in three separate reports delivered to the PAs and EEAC consultants in June 2011. Impact evaluation <http://ma-eeac.org/wordpress/wp-content/uploads/Impact-Evaluation-Final-Report.pdf>, Participant survey results <http://ma-eeac.org/wordpress/wp-content/uploads/Participant-Survey-Results-Final-Report.pdf>, and Secondary market review (with Cadmus) <http://ma-eeac.org/wordpress/wp-content/uploads/Secondary-Market-and-Appliance-Disposal-Report.pdf>.

energy savings values for refrigerators and freezers.² We compare the results of this effort to the 2011 results and to the UEC found in recently completed evaluations of other appliance recycling programs across the nation.

NMR suggests that the PAs and EEAC consultants consider applying the per-unit savings estimates for refrigerators and freezers presented in Table 1 for 2017 filings. They may also consider using the same values as placeholders for planning the 2019 to 2021 program. These placeholders could be replaced with final estimates – to be delivered no later than July 31, 2018 – of UEC, part-use, replacement rates (if included in the study), and per-unit savings for use in final planning and TRM revisions.

Table 1: Suggested Per-unit Savings for 2017 Annual Report

	Refrigerators		Freezers	
	Distribution of Units	Per-unit Savings (kWh)	Distribution of Units	Per-unit Savings (kWh)
Primary	47%	468	N/A	N/A
Secondary Replaced	11%	538	18%	424
Secondary Not Replaced	42%	853	82%	613
Weighted (by distribution)	100%	638	100%	579

Section 1 Literature, Prior Evaluation and TRM Review

1.1 LITERATURE REVIEW

The team conducted a review of recent literature that evaluated appliance recycling programs using the UMP or similar algorithms. Table 2 shows the range and median values of annual unit energy consumption (UEC) found in the recent literature.

Table 2: Literature Review of Annual Unit Energy Consumption (UEC)

Appliance	Range*	Median*
Refrigerator	732-1,194 kWh	1,158 kWh
Freezer	853-1,106 kWh	1,026 kWh

*Sources include: Ameren IL 2015; ComEd IL 2016a; ComEd IL 2016b; Pacific Power 2016; RMP ID 2016; RMP WY 2016; WI FOE 2016; Duke 2015; PA PPL 2015; PSC NM 2016; CA PUC 2014. Full citations listed in Appendix A.

² The Uniform Methods Protocol argues against measuring spillover for recycling programs given their different nature from rebate or direct install programs. See Keeling, J.; Bruchs, D. (2017). *Chapter 7: Refrigerator Recycling Evaluation Protocol. The Uniform Methods Project: Methods for Determining Energy-Efficiency Savings for Specific Measures.* Golden, CO; National Renewable Energy Laboratory. NREL/SR-7A40-68563. <http://www.nrel.gov/docs/fy17osti/68563.pdf>.

1.2 2011 UEC AND CURRENT TRM SAVINGS VALUES

As mentioned above, the current study estimates UEC and per-unit savings based on an approach advocated in the UMP. This approach, described more below, estimates UEC using a regression model that incorporates various characteristics of recycled refrigerators and freezers. In contrast, the only existing study of the Massachusetts Appliance Recycling program was completed in 2011 and covered the 2009 and 2010 program. The 2011 study estimated UEC via approaches advocated at the time by the Department of Energy (DOE) and the American Home Appliance Manufacturers (AHAM) to estimate UEC and per-unit savings.³ The 2011 study yielded the estimates shown in Table 3, which also reports the current TRM values for per-unit savings. The difference in UEC and per-unit savings reflects part-use,⁴ replacement rates, and the characteristics of units that replaced the recycled ones.

Table 3: UEC and Per-unit Savings from 2011 Evaluation and TRM (in kWh)

	Refrigerators			Freezers	
	Primary Replaced	Secondary Replaced	Secondary Not Replaced	Secondary Replaced	Secondary Not Replaced
2011 - UEC ¹	1,035	1,397	1,342	1,101	1,131
2011 – Per-unit Savings ²	531	694	836	596	672
TRM Per-unit Savings	533	696	835	633	

¹ Average of the DOE and AHAM method results as reported in Table 5-1 and Table 5-5 of the original report.

² Adjusted gross savings as reported in Table ES-3 of the original report.

³ NMR is uncertain of the source of minor differences in per-unit savings between the 2011 study and the TRM.

Section 2 Updated UEC and Per-Unit Savings

To calculate the updated UEC and per-unit savings values, the team applied the average values of the units recycled through the Massachusetts program in 2017 to the UMP regression equations for refrigerators and freezers, listed in Sections 2.1 and 2.2 below. For comparison, we also recalculated 2011 UEC using the UMP algorithms. For both years, the team used state average Typical Meteorological Year 3 (TMY3) heating and cooling degree days for the CDD and HDD variables, retaining the percentage of units in unconditioned space as found in the 2011 study (as the literature review revealed that this input varies across the nation). We adjust for part-use and replacement to maintain comparability with the 2011 report. Part-use accounts for recycled units that were not plugged in and turned on for the full year prior to surrender. Replacement occurs for participants who obtain new units to take the place of the recycled one.⁵ The PAs and EEAC consultants must still decide if NMR should update replacement in the full 18-1 Appliance Recycling Study.

³ See the original study for more detail. NMR Group. *Massachusetts Appliance Turn-in Program Impact Evaluation*. <http://ma-eeac.org/wordpress/wp-content/uploads/Impact-Evaluation-Final-Report.pdf>.

⁴ Many of the units recycled in 2009 and 2010 had been idle for more than a year at the time of surrender.

⁵ Evaluators differ on whether they believe energy savings should be adjusted for replacement, as outlined in more detail in the 18-1 Appliance Recycling Draft Stage 3 plan.

2.1 REFRIGERATORS

The team used the following equation to calculate refrigerator UEC:

$$\begin{aligned}
 \text{Refrigerator UEC} &= 365.25 * (0.582 + 0.027(\text{average appliance age}) \\
 &+ 1.055(\% \text{ manufactured before 1990}) + 0.067(\text{average size in cu. ft.}) \\
 &+ -1.977(\% \text{ single - door}) + 1.017(\% \text{ side - by - side door}) \\
 &+ 0.605(\% \text{ primary use}) \\
 &+ .020(\text{interaction \% in unconditioned space and CDD}) \\
 &+ -0.045(\text{interaction \% in unconditioned space and HDD})
 \end{aligned}$$

Table 4 presents the UMP coefficients in Column 1. Column 2 and Column 4 list the average values for the algorithm inputs from the 2011 study and 2017 program tracking data. Column 3 represents the product of Column 1 and Columns 2, and likewise, Column 5 is the product of Column 1 and Column 4. The highlighted rows list the daily UEC (the sum of the rows above) and the annual UEC (daily x 365.25). The UMP-estimated annual UEC of 907 kWh for 2017 was 18% less than the UMP-estimated UEC of 1,106 kWh for 2011. The 2017 estimate falls within the range of UECs found in the recent literature review (Table 2). The vintage of refrigerators serves as the main factor drawing down UMP-estimated UEC in 2017. In 2011, 82% of refrigerators recycled were manufactured before 1990, while in 2017 only 19% were, and the average age of units dropped from 27 years to 19 years. However, the larger size and increased side-by-side configuration of 2017 units and the increase in primary units offset to some extent the age-related UEC reduction.

Table 4. Refrigerator Program Values and UEC Calculation¹

	Col 1	Col 2	Col 3	Col 4	Col 5
Independent Variable	UMP Coef (Daily kWh)	MA 2011 Program Values	UEC 2011 (in kWh) ²	MA 2017 Program Values	UEC 2017 (in kWh)
Intercept	0.582	1.00	0.58	1.00	0.58
Appliance Age (years)	0.027	26.60	0.78	19.22	0.52
Dummy: Manufactured Pre-1990	1.055	0.82	0.86	0.19	0.21
Appliance Size (cubic feet)	0.067	16.80	1.13	19.15	1.28
Dummy: Single-Door Configuration	-1.977	0.00	0.00	0.03	-0.07
Dummy: Side-by-Side Configuration	1.071	0.12	0.13	0.19	0.20
Dummy: Primary Usage Type (in Absence of Program)	0.605	0.22	0.13	0.47	0.28
Interaction: Located in Unconditioned Space * CDDs	0.020	0.19	0.004	0.19	0.004
Interaction: Located in Unconditioned Space * HDDs	-0.045	11.73	-0.53	11.73	-0.53
Before Part-Use Factor - daily			3.03		2.48
Before Part-Use Factor – annual			1,106.52		907.64

¹ We list the UMP coefficients to the third decimal place in keeping with the original document. All other values have been rounded to two decimal places, unless the value was less than 0.01 but greater than zero. The use of multiple decimal places is not mean to imply greater precision but to align with the approaches taken in other jurisdictions.

² The UECs in this Column reflect the application of the UMP algorithm to data reported in the 2011 study. The 2011 study calculated UECs using a different method, and these varied from 1,035 kWh for primary refrigerators to 1,397 kWh for secondary, replaced refrigerators.

Table 5 compares UECs as reported in the 2011 study and UMP-estimated UEC for 2017 for primary/secondary use, part-use, and whether the unit was replaced. Although the 18-1 Appliance Recycling Participant Survey may update part-use and replacement rates, lacking such updates currently, NMR estimated part-use and replacement for 2017 in the following manner:

- **Part-use:** The literature review found part-use factors that ranged from 0.67 to 0.99, with 0.94 serving as the median (meaning households used the units 94% of the time). We applied the median to the 2017 data. In contrast, the 2011 study used survey data to estimate part-use factors for secondary unit, yielding factors of 0.79 for secondary replaced units and 0.62 for secondary non-replaced units.⁶ NMR selected the literature median over 2011 values because the younger age and greater proportion of primary

⁶ The 2011 study captured the first two years of the Appliance Recycling program, and the survey found that many of the units had not been used at all in the year prior to surrender.

units surrendered suggests that part-use has declined over time. The 18-1 Appliance Recycling Participant Survey will yield an updated part-use factor, and NMR will revise these estimates in June 2018.

- **Replacement:** As outlined in the Draft 18-1 Appliance Recycling Stage 3 Plan, the UMP recommends against adjusting UEC for replacement. Therefore, the literature rarely addresses replacement rates, apart from the development of part-use factors. Lacking guidance on how best to adjust UEC for replacement and wanting to mirror the 2011 study for comparability to current TRM values, NMR assumed all primary units were replaced and that the same proportions of secondary units were replaced as in the 2011 study.

Based on these assumptions, the weighted UEC pre-part-use adjustment declined by 25%, from 1,204 kWh to 908 kWh, between 2011 and 2017. However, average per-unit savings has decreased by only 6% or 40 kWh per unit, ranging from 18 kWh increased savings for secondary not replaced units to -158 reduced savings for secondary replaced units. The smaller change in savings relative to UEC reflects the updated part-use factors (0.94 for 2017 vs. 0.79 and 0.62 for 2011) and the fact that UEC reductions due to vintage were offset by increases due to size and door configuration. If the survey yields a smaller part-use factor (i.e., indicating less frequent use) the results could be greater reductions in savings than suggested here.

**Table 5: Comparison of UECs and Per-Unit Savings (in kWh):
2011 Study, 2017 Study, and Current TRM**

	Current Distribution of Units	2011				2017			
		UEC: Pre-part-use	UEC: Post-part-use ¹	TRM Savings ²	Ratio TRM to post-part use	UEC: Pre-part-use ³	UEC: Post-part-use ⁴	Per-unit Savings ⁵	Change in Per-unit Savings
Primary	47%	1,035	1,035	533	0.51	908	908	468	-65
Secondary Replaced	11%	1,397	1,104	696	0.63	908	853	538	-158
Secondary Not Replaced	42%	1,342	835	835	1.00	908	853	853	+18
Weighted (by unit distribution)		1,204	957	678		908	878	638	-40

¹ The part-use factor for secondary replaced = 0.79 and for secondary not-replaced = 0.62.

² Adjusted for efficiency of replacement units, per the 2011 study.

³ Based on UMP method, which treats primary/secondary distinction within the equation.

⁴ Assumed 0.94 part-use factor secondary units.

⁵ Applied the ratio of 2011 post-part-use UEC to TRM savings to the 2017 post-part-use UEC.

2.2 FREEZERS

The team used the following equation to calculate freezer UEC, and the results in Table 6 are structured the same as those in Table 4. The UMP-estimated UEC of 667 kWh for 2017 was 31% lower than the UMP-estimated UEC of 961 kWh for 2011. This is much lower than the range found in the literature (Table 2), because the recycled freezers in Massachusetts tend to be younger and smaller than those surrendered in other jurisdictions. Age and size are also the drivers of the difference between Massachusetts in 2011 and 2017. In 2011, 86% of freezers recycled were manufactured before 1990 and were 31 years old at the time of surrender, while the comparable values in 2017 were 39% and 24 years. The size of recycled freezers decreased from 17 ft³ in 2011 to 15 ft³ in 2017.

$$\begin{aligned} \text{Freezer UEC} = & 365.25 * (-0.955 + 0.045(\text{average appliance age}) \\ & + 0.543(\% \text{ manufactured before 1990}) + 0.12(\text{average size in cu. ft.}) \\ & + 0.298(\% \text{ chest configuration}) \\ & + .082(\text{interaction \% in unconditioned space and CDD}) \\ & + -0.031(\text{interaction \% in unconditioned space and HDD}) \end{aligned}$$

Table 6. Freezer Program Values and UEC Calculation¹

	Col 1	Col 2	Col 3	Col 4	Col 5
Independent Variable	UMP Coef (Daily kWh)	MA 2011 Program Values	UEC 2011 (in kWh) ²	MA 2017 Program Values	UEC 2017 (in kWh)
Intercept	-0.95	1.00	-0.95	1.00	-0.95
Appliance Age (years)	0.04	30.94	1.39	23.52	1.06
Dummy: Manufactured Pre-1990	0.54	0.86	0.47	0.39	0.21
Appliance Size (cubic feet)	0.12	17.27	2.07	15.27	1.83
Dummy: Chest Configuration	0.30	0.19	0.06	0.27	0.08
Interaction: Located in Unconditioned Space * CDDs	0.08	0.23	0.02	0.23	0.02
Interaction: Located in Unconditioned Space * HDDs	-0.03	13.57	-0.42	13.57	-0.42
Before Part-Use Factor - daily			2.63		1.83
Before Part-Use Factor – annual			961.08		667.35

¹ We list the UMP coefficients to the third decimal place in keeping with the original document. All other values have been rounded to two decimal places, unless the value was less than 0.01 but greater than zero. The use of multiple decimal places is not mean to imply greater precision but to align with the approaches taken in other jurisdictions.

² The UECs in this Column reflect the application of the UMP algorithm to data reported in the 2011 study. The 2011 study calculated UECs using a different method, and these varied from 1,035 kWh for primary refrigerators to 1,397 kWh for secondary, replaced refrigerators.

Likewise, Table 7 follows a similar format to Table 5, and makes similar assumptions about part-use and replacement rates as for refrigerators. The weighted UEC pre-part-use adjustment for freezers declined by 41%, from 1,126 kWh to 667 kWh, between 2011 and 2017. Per-unit savings decreased by an average of 13% or 84 kWh per unit, ranging from -50 kWh for not replaced units to -239 kWh for replaced units. Again, the age and size of units account for the decrease, but the smaller change in savings relative to UEC reflects the updated part-use factors (0.94 for 2017 vs. 0.89 and 0.60 for 2011). As with refrigerators, these results could change pending the outcomes of the participant survey.

**Table 7: Comparison of UECs and Per-Unit Savings (in kWh):
2011 Study, 2017 Study, and Current TRM**

	Current Distribution of Units	2011				2017			
		UEC: Pre-part-use	UEC: Post-part-use ¹	TRM Savings ²	Ratio TRM to post-part use	UEC: Pre-part-use ³	UEC: Post-part-use ⁴	Per-unit Savings ⁵	Change in Per-unit Savings
Replaced	18%	1,101	980	663	0.68	667	627	424	-239
Not Replaced	82%	1,131	679	663	0.98	667	627	613	-50
Weighted (by unit distribution)		1,126	733	663		667	627	579	-84

¹ The part-use factor for secondary replaced = 0.89 and for secondary not-replaced = 0.60.

² Adjusted for efficiency of replacement units, per the 2011 study. TRM also uses the same savings rates for both replaced and not replaced freezers.

³ Based on UMP method, which treats primary/secondary distinction within the equation.

⁴ Assumed 0.94 part-use factor secondary units.

⁵ Applied the ratio of 2011 post-part-use UEC to TRM savings to the 2017 post-part-use UEC.

Appendix A

A.1 REVIEW OF PROGRAM TRACKING DATA

The Appliance Recycling Centers of America, Inc. (ARCA) administered the MassSave[®] appliance recycling program in 2017 and completed. The rebate form included the following variables:

- Primary or secondary usage of rebated unit (units were considered primary if they were located in a kitchen, and secondary otherwise)
- Unit type (freezer or refrigerator)
- Unit door configuration (top freezer, bottom freezer, side-by-side or single door for refrigerators and chest or upright for freezers)
- Unit age in years
- Unit size in cubic feet
- Customer name, address, and account number
- The date of unit pickup, rebate submittal, rebate completion, and PA billing
- The incentive type (\$50 or \$100 check)
- Unit brand
- Unit model number
- Unit serial number

NMR used the information in green font to calculate the UEC and per-unit savings estimates presented in this memo. The addition information will support later impact and process evaluation work, upon finalization of the 18-1 Appliance Recycling Evaluation Stage 3 Plan.

A.2 DISTRIBUTIONS AND FREQUENCIES OF KEY VARIABLES

The following tables and graphs describe the most important variables for inclusion in the UMP algorithms. Note that the sample sizes change due to missing data.

Figure 1. Distribution of Recycled Refrigerator Age (Count = 15,512)

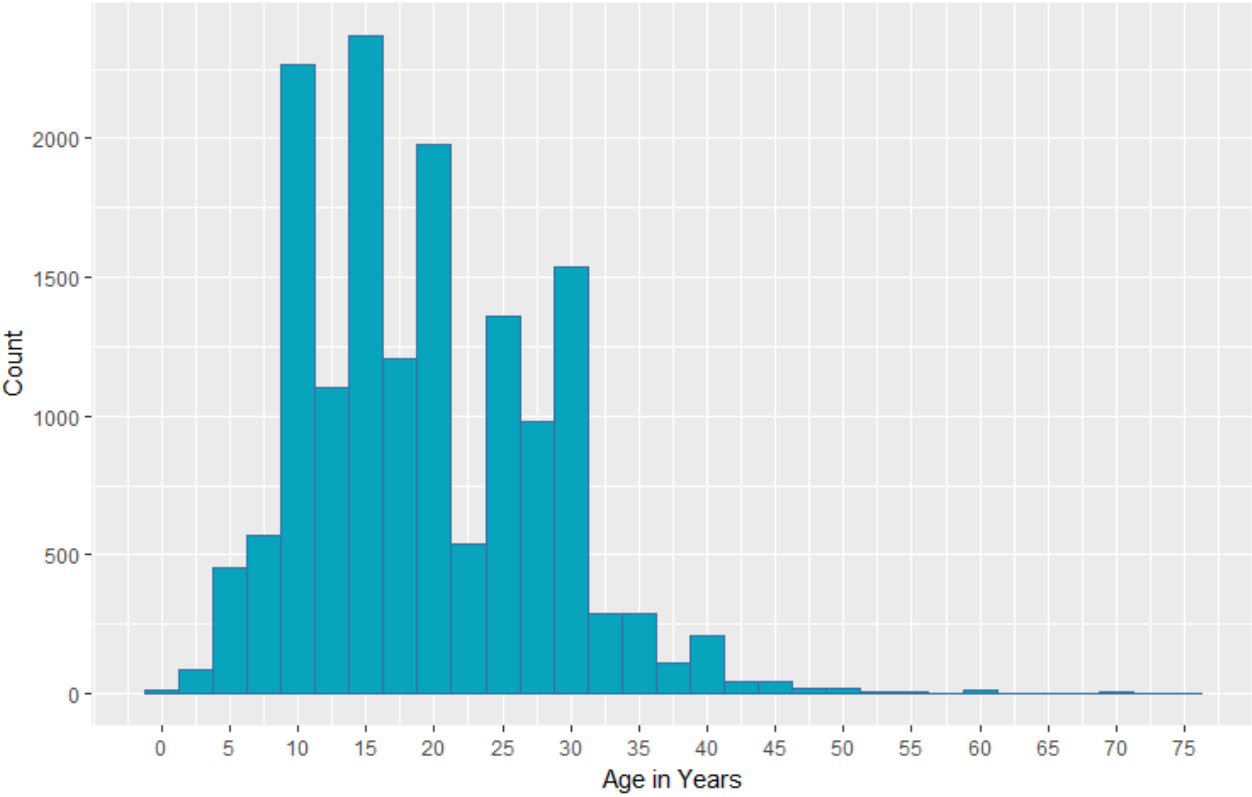


Figure 2. Distribution of Recycled Freezer Age (Count = 2,657)

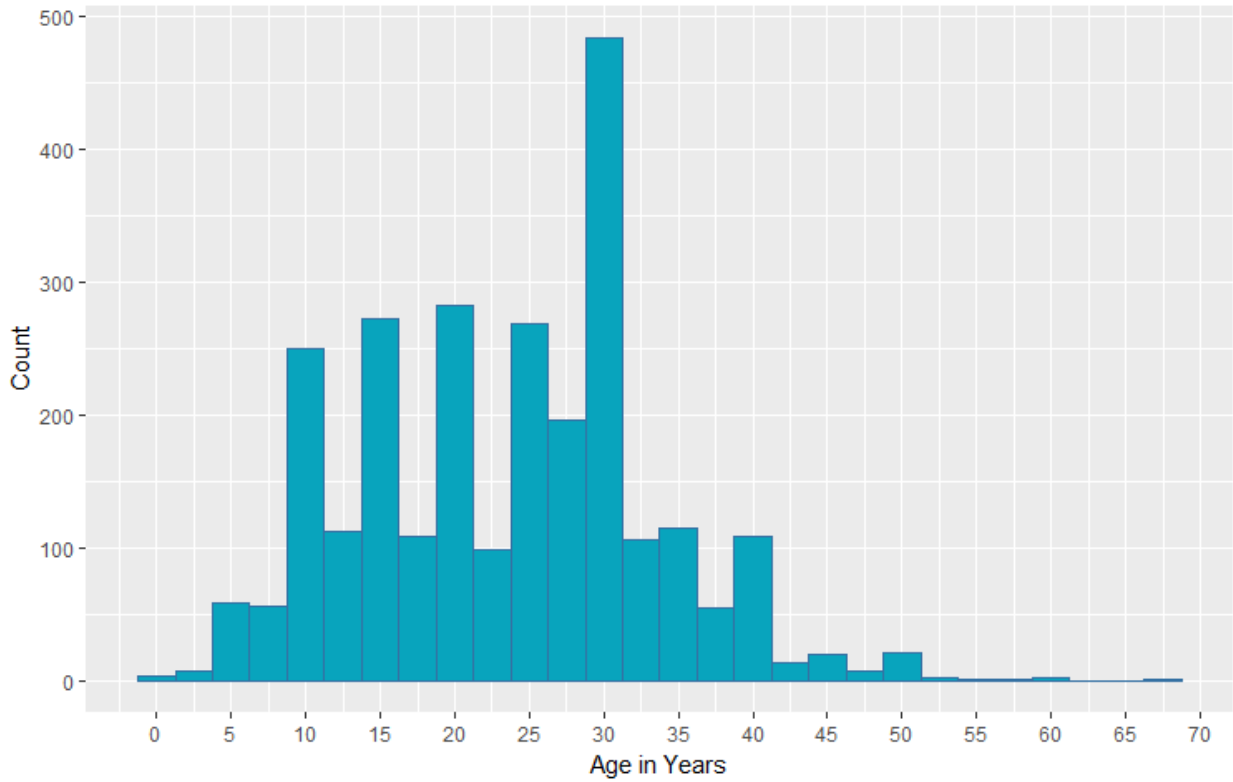


Figure 3. Distribution of Recycled Refrigerator Size (Count = 15,637)

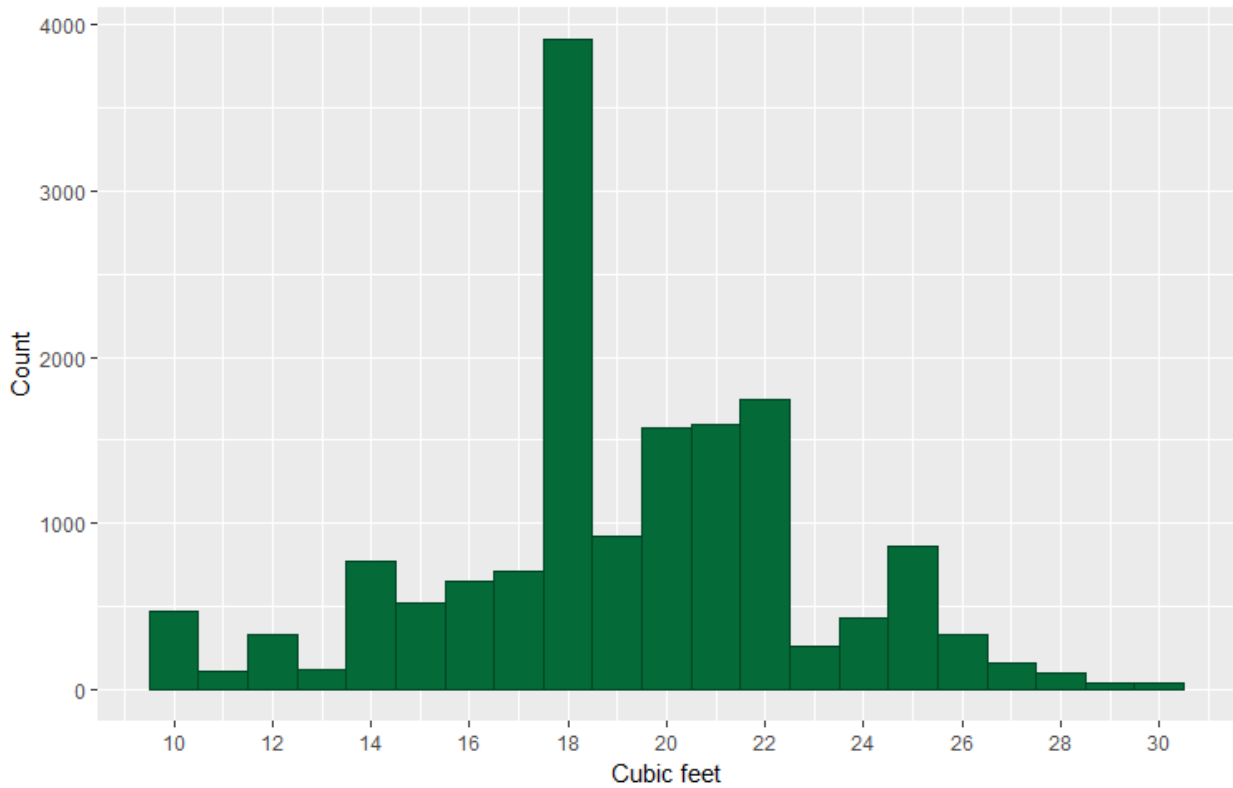


Figure 4. Distribution of Recycled Freezer Size (Count = 2,663)

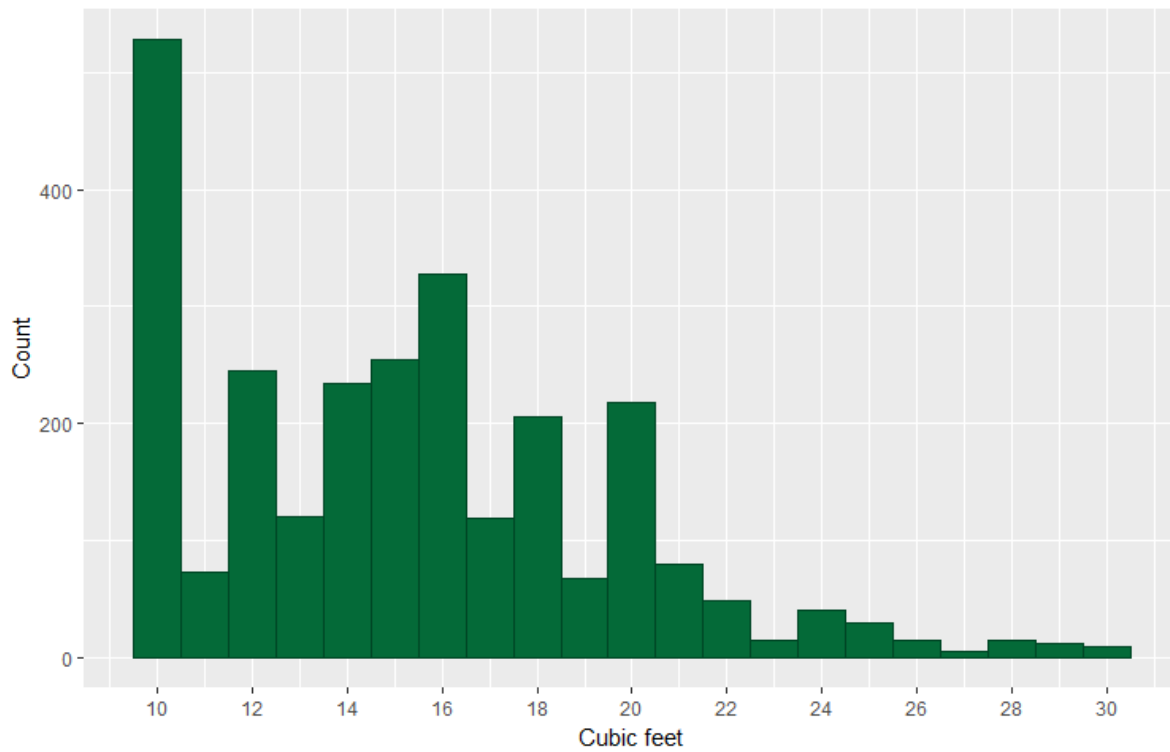


Table 8. Recycled Unit Year of Manufacture

Year of Manufacture	Refrigerators	Percentage	Freezers	Percentage
Pre-1990	3,014	19%	1,037	39%
1990 and later	12,498	81%	1,620	61%
Total	15,512		2,657	

Table 9. Recycled Unit Configuration

Unit Type	Door Configuration	Count	Percentage
Refrigerators	Bottom Freezer	1,120	7%
	Side-by-side	2,970	19%
	Single door	537	3%
	Top freezer	11,010	70%
	Total Refrigerator	15,637	
Freezers	Chest	726	27%
	Upright	1,937	73%
	Total Freezer	2,663	

Table 10. Recycled Unit Use

Unit Use	Refrigerators	Percentage	Freezers	Percentage
Primary	7,325	47%	464	17%
Secondary	8,311	53%	2,199	83%
Total	15,636		2,663	

A.3 PER-UNIT SAVINGS LITERATURE SOURCES

Condensed Citation	Full Citation
Ameren IL 2017	Opinion Dynamics. Impact and Process Evaluation of 2015 (PY8) Ameren Illinois Company Appliance Recycling Program. February 2017.
ComEd IL 2016a	Navigant, Itron. ComEd Fridge & Freezer Recycling Program. Presented to Commonwealth Edison. February 2016.
ComEd IL 2016b	Navigant, Itron. ComEd Fridge & Freezer Recycling Program. Presented to Commonwealth Edison. November 2016.
Pacific Power 2016	Cadmus. See ya later, refrigerator®: Program Evaluation Report 2013–2014. Prepared for Pacific Power. February 2016.
RMP ID 2016	Cadmus. Rocky Mountain Power Idaho See ya later, refrigerator®: Program Evaluation Report 2013–2014. April 2016.
RMP WY 2016	Cadmus. Rocky Mountain Power Wyoming See ya later, refrigerator®: Program Evaluation Report 2013–2014. April 2016.
WI FOE 2016	Cadmus. Focus on Energy Calendar Year 2015 Evaluation Report Volume II. Prepared for Public Service Commission of Wisconsin. May 2016.
Duke 2015	Opinion Dynamics. Duke Energy Appliance Recycling Program. Prepared for Duke Energy Progress and Duke Energy Carolinas. September 2015.
PA PPL 2015	Cadmus. Annual Report Program Year 6: June 1, 2014 –May 31, 2015 Presented to: Pennsylvania Public Utility Commission. Prepared for PPL Electric Utilities. November 2015.
PSC NM 2015	ADM. Evaluation of 2016 Public Service Company of New Mexico Energy Efficiency & Demand Response Portfolio. April 2017.
CA PUC 2014	DNV GL. 2010-2012 Appliance Recycling Program Impact Evaluation. October 2014. Prepared for California Public Utilities Commission.