EVALUATION OF THE ENERGY AND ENVIRONMENTAL EFFECTS OF THE CALIFORNIA APPLIANCE EARLY RETIREMENT AND RECYCLING PROGRAM

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Abstract

The California Appliance Early Retirement and Recycling Program, funded by California Senate Bill SBX 1-5, was administered by the California Public Utilities Commission (CPUC). Appliance Recycling Centers of America (ARCA) was selected by the CPUC to implement the program, and ARCA had responsible for all elements of program delivery. This program is one of a series of similar programs implemented over the last ten years in California, which have become increasingly important in efforts to reduce peak demand and promote energy efficiency. However, substantial debate continues to surround key elements of program impact.

ICF Consulting recently conducted an evaluation of the energy and environmental impacts of this program. This paper briefly presents the high-level conclusions drawn about the impact and cost-effectiveness of the program, but focuses on the key areas of uncertainty regarding estimation of program energy impacts. In particular our evaluation found a wide discrepancy between unit energy consumption values estimated using a previously-developed statistical model and estimates derived from a small sample of on-site metering. Even when measured against the lowest plausible values for unit energy consumption and the net-to-gross ratio the program was cost-effective though much less so than often estimated. It is clear that, despite over a decade of practice, evaluations of appliance recycling programs continue to suffer from significant uncertainty in key performance parameters. The paper also summarizes the environmental impacts of the recycling program.

Introduction

ICF Consulting was retained by the Appliance Recycling Centers of America (ARCA), under contract to the California Public Utilities Commission (CPUC), to prepare an evaluation of the California Appliance Early Retirement and Recycling Program (the Program). This program is overseen by the CPUC with funding received under California Senate Bill No.5 (Chapter 7, 1st Extra-Ordinary Session, (SBX1 5) signed 8/11/2001), and was implemented by ARCA. The Program provided modest incentives to customers to turn-in functioning, secondary or inefficient refrigerators, freezers and room air conditioners. ARCA collected the appliances from the homes of participants, transferred them to its recycling center in Compton, California, disassembled them and extracted all hazardous and otherwise regulated materials and substances. In addition, the facility processes polyurethane foams, used as refrigerator and freezer insulation, to remove CFCs used as foam blowing agents. Virtually all of the ferrous and nonferrous metals, glass and plastic were recycled, with the remainder disposed of in municipal solid waste facilities. The program evaluation included several primary tasks:

- Summarize the relevant literature regarding past programs in California.
- Evaluate the energy saving and demand reduction impacts of the Program based on ARCA/CPUC assumptions and Program data. This task included an assessment of the historic penetration of

appliance retirement/recycling programs and an estimate of future potential. Our assessment suggests that since their inception, retirement programs in California have reached under 10% penetration for secondary refrigerator removal, and under 7% of stand alone freezer removal. Considering just secondary refrigerators, there is huge remaining market potential, which we estimate at over 1.5 million units.

- Perform a due diligence review of program impact assumptions, including those related to unit energy consumption (UEC), unit demand reduction, unit remaining lifetime and net-to-gross (NTG) ratios, and make recommendations with respect to future impact evaluations and approaches.
- Assess the environmental impacts of the Program, including consideration of ozone-depleting substances.

The charge to ICF Consulting was to perform a due diligence evaluation as opposed to developing independent estimates. This charge required us to critically review approaches and estimates to date and highlighted a number of important issues in how energy impacts of retirement programs are estimated.

Program Energy Impacts

The four key elements of the program energy and demand savings computation are as follows:

- Unit annual energy consumption (UEC) – the annual kWh consumed by a refrigerator, freezer or room air conditioner when it is in use.
- Unit peak demand – the peak kW of a population of refrigerators, freezers or room air conditioners during system peak periods.
- Unit Lifetime – the number of years of remaining use that is expected for a unit when it is recycled.
- Adjustment Factor (Part-Use and Net-to-Gross Factors) – the adjustments used to estimate the net impact of the program by taking into account what program participants would have done in the absence of the program.

The first step in determining the appropriate values for each of these parameters was to review the relevant program evaluation literature to understand past approaches that have been taken, and the parameter values that resulted.

Energy Impacts Literature Review

This section summarizes several refrigerator/freezer retirement and recycling program evaluations that were relevant for use in validating the estimated savings and key assumptions from the CPUC Early Retirement Program. These reports include:

- *Impact Evaluation of the Spare Refrigerator Recycling Program, CEC Study #537, Final Report,* Xenergy, April 30, 1998, (Xenergy 1998)
- *Refrigerator/Freezer UEC Estimation, 1996, ARCA/SCE Turn-in Program. In Support of Xenergy Inc's Evaluation of the 1996 Appliance Recycling Program,* Athens Research, May 1, 1998

- *Impact Evaluation of 1994 Spare Refrigerator Recycling Program, Project ID 515, Final Report,* Xenergy, February 27,1996, (Xenergy 1996)
- *Extended Impact Evaluation of the Spare Refrigerator Recycling Program, Final Report, CEC Study ID No. 515*, Xenergy, February 27, 1997, (Xenergy 1997)
- *A Profile of a Refrigerator Recycling Program,* Sacramento Municipal Utility District (SMUD), Heschong Mahone Group and RLW Analytics, Summer 2002
- *The Multi-Megawatt Refrigerator/Freezer Recycling Summer Initiative Program, Final Report,* ARCA, December 2001
- *Audit of Energy Efficiency and Low-Income Assistance Funds,* Barrington-Wellesley Group, April 11, 2002

The following table shows the values used for the key energy impact parameters for each program evaluation reviewed. These results indicate that estimates of these parameters have ranged widely, particularly regarding the annual UEC and net-to-gross values.

Table 1. Program Evaluation Energy Impact Parameters

Program	Evaluator	Avereage UEC (kWh)	Peak Demand Reduction (kW)	Net-to-Gross Ratio	Net Savings Per unit (kWh)	Net Peak Reduction (kW)
CPUC SBX-5:	*ARCA, Ex-Ante Assumptions*					
Refrigerators		2,148	0.33	0.8	1,718	0.264
Freezers		2,058	0.31	0.8	1,646	0.248
SMUD 2001-2002:	*Heschong Mahone Group, SMUD, RLW Analytics*					
Refrigerators		1,552	n/a	0.8	1,242	n/a
Freezers		1,501	n/a	0.8	1,201	n/a
ARCA Summer '01 Initiative:	*ARCA, Methodology 1*					
Refrigerators		1,593	0.28	n/a	n/a	n/a
Freezers		1,593	0.28	n/a	n/a	n/a
	ARCA, Methodology 2					
Refrigerators		2,148	0.33	0.8	1,718	0.264
Freezers		2,058	0.31	0.8	1,646	0.248
ARCA Summer '01 Initiative:	*Barrington-Wellesley Group*					
Refrigerators		2,148	0.33	0.53	1,141	0.175
Freezers		2,058	0.31	0.57	1,182	0.177
SCE 1996:	*Xenergy (Xenergy 1)*					
Refrigerators		2,148	0.33	0.53	1,141	0.175
Freezers		2,058	0.31	0.57	1,182	0.177
SCE 1994:	*Xenergy - Initial Report (Xenergy 2)*					
Refrigerators		1,593	0.245	0.423	674	0.104
Freezers		1,250	0.191	0.379	474	0.072
SCE 1994:	*Xenergy - Extended Study Report (Xenergy 3)*					
Refrigerators		1,866	0.285	0.614	1,146	0.175
Freezers		1,589	0.243	0.649	1,031	0.158

Annual Unit Energy Consumption

Several methods exist for estimating the annual energy consumption of appliances, including manufacturer's estimates, billing analysis, in-situ monitoring, and laboratory monitoring. Using manufacturer's estimates requires that the manufacturer ID number be available for each unit in question. This number can then be tied to manufacturer's UEC estimate, using a database such as that provided by the Association of Home Appliance Manufacturers (AHAM). This process, however, can be difficult and may yield a low ID number match rate (RLW Analytics, 2000). ARCA did not track unit manufacturer ID numbers of units removed, rendering this approach impossible. Billing analysis was also not possible due to limitations in time and information.

Our approach relied on both a statistical analysis of collected units as well as on-site monitoring of a limited number of refrigerators that were to be collected by ARCA. As described below, these two methods yielded very different results.

The statistical approach used coefficients estimated in a model drawing upon laboratory measurements of several samples of refrigerators conducted during the 1990s in the course of evaluating several Southern California Edison refrigerator early retirement programs. The statistical methodology was designed by Athens Research (Athens Research, 1998). We consulted with Athens Research to re-create and apply this methodology using the specific characteristics of the units removed in the current program. The methodology employed by Athens Research involves two steps: (1) A regression analysis using the results of two unit metering studies, and (2) Using the results of that analysis to assign each unit removed in the program, an estimated UEC value based on unit characteristics including age, amperage, size, configuration, and defrost type.

The two unit metering studies, conducted in 1998 and 1996, consisted of a combined 1,313 refrigerators and freezers sampled from various ARCA programs and locations in the US. The studies used DOE-protocol metering, conducted in a laboratory setting. DOE-protocol metering is designed to yield an estimated annual UEC value for each unit by running the unit at steady state in an ambient temperature of 90 degrees Farenheit. This temperature, warmer than average ambient in-situ conditions, is intended to account for daily ambient temperature fluctuation and door openings.

We created Visual Basic routines that assigned each refrigerator and freezer from the ARCA program tracking database a UEC value based on its characteristics. The following tables summarize the average UEC values by unit category, and indicate first-year overall average values of 2,162 kWh for freezers, and 2,163 kWh for refrigerators. The tables show the weighted average value for all units within each category:

Table 2. Average Refrigerator UEC Values by Configuration and Defrost Type

Model Type	Defrost Type	Average UEC
Bottom Freezer	Frost Free	2,497
	Manual	2,170
	Part Frost Free	2,165
Bottom Freezer Total		**2,463**
Side-by-Side	Frost Free	2,848
	Manual	1,077
	Part Frost Free	1,063
Side-by-Side Total		**2,643**
Single Door	Frost Free	2,409
	Manual	938
	Part Frost Free	1,373
Single Door Total		**1,651**
Top Freezer	Frost Free	2,128
	Manual	1,191
	Part Frost Free	1,166
Top Freezer Total		**2,023**
Refrigerator Total		**2,163**

Table 3. Average Freezer UEC Values by Configuration and Defrost Type

Model Type	Defrost Type	Average UEC
Chest	Frost Free	2,426
	Manual	1,482
	Part Frost Free	1,496
Chest Total		**1,882**
Upright	Frost Free	2,904
	Manual	1,856
	Part Frost Free	1,834
Upright Total		**2,330**
All Freezers		**2,162**

The first-year average values of 2,162 kWh for freezers and 2,163 kWh for refrigerators are greater than the values used by ARCA by 0.7% for refrigerators (from 2,148 kWh) and 5% for freezers (from 2,058 kWh) in its estimates of program impact. In addition, however, we accounted for unit performance degradation over time in projecting overall lifetime savings. The regression analysis developed by Athens Research includes consideration of the effect of unit age in determining the UEC value. Since we have used this analysis to develop UEC estimates for every unit removed in the program, it is possible to adjust the first-year UEC estimates for each additional year that a unit would have otherwise been in expected operation.

Based on the limited available body of literature regarding room air conditioner programs, it has been difficult to establish a sound estimate of room air conditioner UEC that would apply statewide. Based on room air conditioner load shapes presented in the Quantum Consulting report *1996 Residential Appliance End-Use Study* (Quantum, 1998), the average room air conditioner UEC in SCE's service territory is estimated to be 527 kWh/yr. Since room air conditioner use is highly weather-sensitive, it is likely that the average value would vary across service territories. Nevertheless, absent better information, we suggest using this value until further targeted study can be conducted. Note that this value is significantly higher than the Program's working estimate of 125 kWh/year.

Our evaluation also included the review of the results of on-site monitoring of 40 units completed by ADM Associates. The intent was to monitor units in their original positions prior to their removal by ARCA. For a variety of reasons related to difficulties in drawing the sample and the location of the units when ADM arrived to monitor them, we do not consider the sample to have been random and, therefore, do not believe the monitoring yielded statistically valid results. Nevertheless, the results were compelling. The weighted average UEC value estimated from the on-site monitoring sample was 1,024 kWh/year; less than half the value estimated using the statistical methodology. Although we are not able to conclude that the monitoring sample was a statistical match with the population of units collected by the Program, the characteristics of the sample and of the population were quite similar. When we tested just the monitored 40 units using the statistical method, the wide variance in UEC estimates remained. Given that the UEC values estimated for the monitored units corresponded much more closely to what we would have expected for these units, we concluded that the statistical approach, at least as it is based on the existing laboratory metering samples, does not yield accurate estimates of unit energy consumption. Table 4 summarizes the UEC values estimated from the sample of monitored units that were found in conditioned space.

Table 4. Average Monitored Refrigerator UEC Values by Configuration and Defrost Type

Model Type	Defrost Type	Average UEC
Bottom Freezer	Frost Free	623
Side-by-Side	Frost Free	1,799
	Manual	1,348
Single Door	Manual	709
Top Freezer	Frost Free	947
	Manual	1,145
All Refrigerators		**1,024**

Unit Peak Demand Reduction

While the Program has historically focused on reducing energy consumption, the peak demand reduction aspect of the Program has become increasingly important. Past program evaluations have used a load-factor assumption to derive peak demand reduction impacts based on the annual UEC value, as follows:

Unit peak demand = (Full-Year UEC / 8760 hours) / (Load Factor)

We agree that this approach is valid and effective. The challenge in applying this approach is deriving load factor estimates that are appropriate for the unit population in question.

For its earlier evaluations of Southern California Edison programs, Xenergy (Xenergy 1996, 1997, 1998) developed an estimated load factor based on analysis conducted by AAG & Associates in the report titled *Analysis of SCE and PG&E Refrigerator Load Data*, (AAG & Associates, 1995). This load data study includes new refrigerator population load shapes that indicate a population load factor of approximately 74.6%. Xenergy used this value in several evaluations of the SCE recycling program. As a report relating to efficient refrigerator rebate programs, the AAG & Associates Study only included analysis of new refrigerators. It does not include any data describing how the load factor for older refrigerators would likely compare to that of newer units. The report does state qualitatively that newer, more efficient refrigerators tend to consume a higher proportion of their annual consumption during summer peak demand periods, presumably because improvements in refrigerator efficiency have focused on improved insulation as opposed to compressor efficiency. This would seem to indicate that populations of refrigerators including old, inefficient units will likely have higher load factors than the populations studied by AAG & Associates. Additionally, the report does not include any information about freezers.

We obtained and analyzed whole-population load shape data from Southern California Edison, representing the entire installed base of units. These load shapes in the Quantum Consulting report *1996 Residential Appliance End-Use Study* (Quantum Consulting, 1998) indicate population load factors of 80.19% and 76.08% for refrigerators and freezers, respectively. In addition, this report indicates a load factor of 17.07% for room air conditioners. We believe that the Quantum Consulting SCE load shape data, which consider entire populations of refrigerators and freezers, including old, inefficient units, are more appropriately applied than the AAG & Associates load shape data, which only consider new units.

Using the statistical approach to derivation of UEC values, the estimated peak impacts of the ARCA program would be 0.308 kW per unit. Based on the UEC values estimated from the on-site monitoring sample, the per-unit impact would fall to 0.146 kW. Assuming the validity of the approach to estimating peak impact, and consistent with the discussion above, we believe the 0.146 kW estimate to be more indicative of actual program impacts. However, we recommended to the CPUC that it support an effort to directly monitor peak impacts given the increasing importance of peak reduction objectives.

Net-to-Gross Ratio

A critical component of the evaluation was to estimate the net energy and demand savings for the program. The net savings adjusts gross savings for free-ridership and unit part-use. Free riders typically are defined as those participants who would have recycled their appliance (or otherwise permanently removed their appliance from the grid) even if the program had not existed. Part-use refers to the percentage of time that units that would otherwise not have been recycled would have actually been in use. The net-to-gross and part-use ratios are critical, and yet challenging components of evaluating program impacts. The key question, of course, is how program participants would have behaved in absence of the program.

To date, the approach to this issue has been controversial. The CPUC in its Energy Efficiency Policy Manual has suggested a default net-to-gross ratio of 0.8, the value used by ARCA and SMUD in evaluating programs, and by utilities in assessing ex ante cost effectiveness. The most recent departure from this default value is the net-to-gross estimation methodology developed for Xenergy's SCE 1996 Program Evaluation (Xenergy 1998). This methodology yielded values of 0.53 and 0.57 for refrigerators and freezers, respectively. Because these values are such a significant departure from the CPUC-specified 0.8, and have a large impact on attributed program results, some resolution to the debate is critical.

The Xenergy net-to-gross methodology uses the following general framework:

$$NTG = A * U,$$

where

A = attribution factor, disposition of recycled unit in absence of program
U = part use factor, percent of time that unit would actually have been in use

For units that would otherwise have been disposed, the dispositions considered include destruction, transfer outside the territory in question, and transfer within the territory in question. Detailed surveys of program participants, purchasers of used appliances, and consultation with secondary market representatives were used to develop the various disposition percentages and associated attribution factors.

While the SCE 1996 Program Evaluation net-to-gross and part-use analyses included complex survey logic and instruments, we conclude that it is not appropriate a priori, simply to apply the results derived in that study to other program evaluations. For one, this would imply that the participants in the program in question would behave identically to the program participants from the 1996 SCE Program. In addition, using the results from the SCE Program would imply that the ratio of primary to secondary units would be constant between the two programs. Since ARCA did not track whether units removed in any program were, in fact, primary or secondary as part of this program, this assumption is impossible to validate. We attempted to replicate the methodology used by Xenergy (Xenergy 1998) to examine the impacts of a range of alternative assumptions. Based on information available, we estimated that the range of NTG ratio values most likely would be between 0.47 and 0.62, significantly below the default value of 0.80. We caution, however, that the values used for subsequent evaluation should be based on a more complete re-estimation, using the Xenergy methodology as a starting point.

Unit Remaining Lifetime

ARCA has previously assumed that all units removed by the program would otherwise have an expected remaining lifetime of 6 years, the default assumption used by the CPUC. While straightforward in implementation, this approach avoids the fact that the units removed in any program will have a distribution of ages, each of which ought to have a unique remaining life expectation. We investigated two other approaches for estimating the lifetime for each unit. The first (Method 2 below) determines an average lifetime based on a review of the literature, then uses this lifetime to assign each unit in the ARCA tracking database an expected remaining lifetime based on its age, as follows:

Expected remaining lifetime = Average Lifetime – Unit Age

Units that are older than the average unit lifetime would simply be assigned a fixed minimum value. This improves upon the ARCA approach by assigning the appropriate expected life to units that are younger than an average expected life. The shortcoming of this approach is that units that are older than the average age are still simply assigned a single value.

The preferred approach (Method 3 below) to estimating expected unit lifetime would be to specify a "survival function" that estimates the remaining expected lifetime of a unit based on its current age. The survival function approach has been used to estimate refrigerator retention (SDG&E, 1999), and could be estimated using the observed age distribution of the population of refrigerators and freezers in California along with sales data. The age distribution can be estimated from the Statewide Lighting and Appliance Saturation Study, conducted by RLW Analytics, discussed above. Historical state-level sales data, however, remain elusive. We attempted to obtain historical sales data through the Association of Home Appliance Manufacturers (AHAM), but were unable to obtain California-specific data. It is unclear whether such data in fact exist.

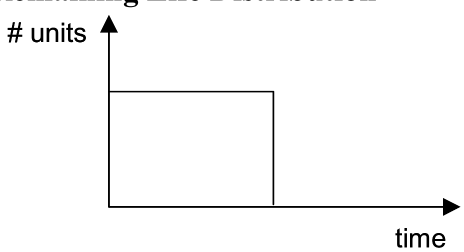
The three methods for estimating remaining life and their impact on lifetime UEC estimation are summarized here graphically:

Method 1: ARCA / CPUC Method – Fixed Remaining Life

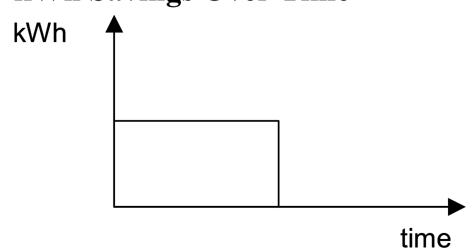
This method assumes a fixed expected remaining life of 6 years, and assumed fixed UEC impact over those six years.

Exhibit 1: Fixed Remaining Life Distribution and Savings

Remaining Life Distribution



kWh Savings Over Time

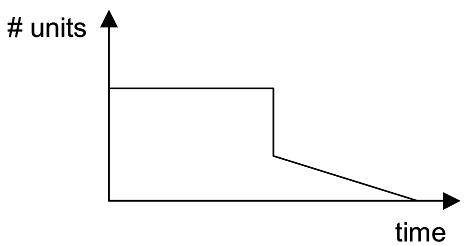


Method 2: Computed Remaining Life

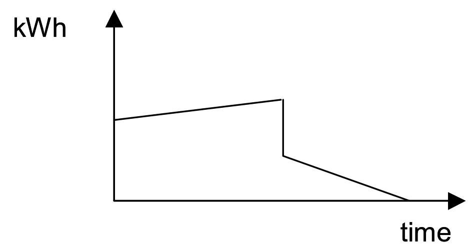
This method assumes that each unit's expected life is equal to the difference between average unit lifetime and the unit's age at the time of removal. If the removed unit has already exceeded the average lifetime, an fixed expected life is assigned. Addressing the expected remaining life of each individual unit also enables assignment of unit performance degradation factors, reflected in the increasing kWh savings over the early years.

Exhibit 2: Fixed Remaining Life Distribution and Savings

Remaining Life Distribution



kWh Savings Over Time

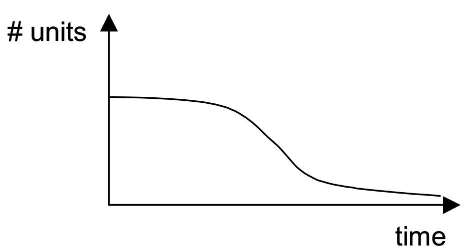


Method 3: Survival Function

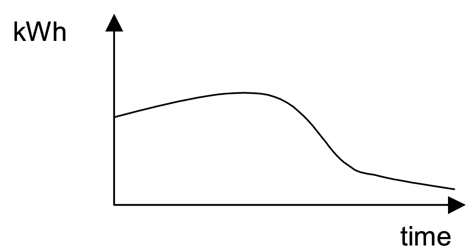
This method is based on a function that represents an expected distribution of expected remaining lives over time. This would enable smooth ramping of program impacts over time.

Exhibit 3: Fixed Remaining Life Distribution and Savings

Remaining Life Distribution



kWh Savings Over Time



Based on historical sales data constraints, we have elected the second approach to estimating remaining useful life. We have used average unit lifetime data from the Lawrence Berkeley Laboratory report *Energy Data Sourcebook for the U.S. Residential Sector* (LBL, 1997), as summarized below:

Table 5. LBL Unit Lifetime Estimates

	First Ownership	Full Life
Refrigerators	15	19
Freezers	12	19
Room A/C	10	13

The report presents average value estimates for both first owner lifetime and full lifetime. Based on this data, we have assumed an average expected full lifetime of 19 years for both refrigerators and freezers, and 13 years for room air conditioners. In addition, we have accepted the initial assumed six years life per unit serves as a reasonable approximation of remaining life of units already exceeding their initial expected life. In the future, development of a 'survival function' that defines the probabilistic lifetime distribution of units over time would allow for the best method of addressing this issue. This function could be developed if historic sales of appliances into California were known. We have suggested that the CPUC take an active role in procuring this data, either through AHAM or by working directly with manufacturers.

Cost-Effectiveness Summary

Based on our due diligence review, we estimated that the Program would be cost-effective under a wide range of assumptions with respect to unit energy consumption, net-to-gross ratio and unit lifetime. Using what we consider lowest reasonable values for unit energy consumption (1,024 kWh/year) and NTG ratio (0.47), the overall program benefit-cost ratio is 1.75. Using the highest values that we found in our review (2,166 kWh/year and 0.8 NTG ratio), the benefit-cost ratio would be 5.01.

Program Environmental Impacts

Previous program evaluations in California have not addressed the environmental benefits associated with early retirement and appropriate recycling of appliances. This evaluation investigated benefits associated with several types of pollutants:

- Ozone Depleting Substances (ODS): ODS such as CFC-12, the refrigerant contained in older household refrigerators and freezers, CFC-11, contained in foam insulation in some refrigerators and freezers, and HCFC-22, the refrigerant in some residential air-conditioning equipment, have been shown to lead to depletion of the stratospheric ozone layer.
- Mineral Oils: Used to lubricate the compressor in some household refrigeration and air-conditioning equipment, mineral oils pose a number of health risks, including various cancers.
- Persistent, Bioaccumulative, and Toxic Pollutants (PBTs): Pollutants which resist degradation in the environment have been linked to a wide range of health effects. PBTs used in refrigerator and freezer manufacturing include polychlorinated biphynels (PCBs) and mercury.

Using unit age information from ARCA's Program tracking database, the following program environmental impacts were estimated:

Table 5: Summary of Environmental Benefits

Chemical removed from service	Amount
Reclaimed ODP emissions (leak and foam)	13,686 ODP kg
PCBs	1,119 kg
Mercury	202 kg
Mineral Oil	15,709 kg

Conclusions

Based on our evaluation we concluded that the ARCA SBX1 5 Program was cost-effective under the entire range of plausible assumptions regarding unit energy savings, unit remaining life, and net-to-gross ratio. Our review of applicable literature combined with limited on-site monitoring reveals a wide range of possible values for key impact parameters. In particular, the wide range of UEC estimates begs for a more focused effort, based on matched samples of on-site and laboratory monitoring, to produce defensible, robust estimates. In addition, refinement of the NTG ratio for statewide programs should receive near-term attention. Refinement of the net-to-gross methodology to explicitly accommodate primary and secondary units, concurrent with tracking of all units as primary or secondary, would be of great value. The fact that benefit-cost ratios vary by almost a factor of five depending on which assumptions one uses, suggests that, despite over a decade of analysis, the state-of-the-art leaves something to be desired.

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