A Refrigerator Replacement Feasibility Study at the University of California, Berkeley

Ryan Dash

Abstract This study analyzes the energy reduction potential and funding mechanisms of a refrigerator replacement program on the campus of the University of California, Berkeley. Since newer models of refrigerators require much less energy than older models, replacing these older ones could greatly cut energy consumption, which leads to less money spent on the electricity bill and fewer greenhouse gas emissions. However, refrigerators are unlikely to be replaced without intervention by the University's central administration because departments do not pay their own energy bills and thus do not see any of the savings. I used energy consumption data obtained from a sampling of refrigerators on campus and compared this with the energy consumption of an assumed replacement, using assumptions for energy deterioration, energy prices, and discount rates, and rebates offered by Pacific Gas and Electric. I found that the payback period could be as low as eight years, soon enough for the University to seriously consider a replacement program. Campus-wide, 70,245 kilowatt-hours of electricity could be saved yearly with such a program, abating 20.5 tons of carbon dioxide in the process. This study also examines department purchasers' willingness to pay for newer refrigerators through an electronically administered survey. Respondents were generally environmentally conscientious, and 80% were willing to replace their refrigerator when offered a 75% subsidy. In general, I found a refrigerator replacement project to be both financially and environmentally beneficial for the University. These results could be applied to other universities in the United States.

Introduction

Using more energy efficient appliances can be one of the most effective and least costly ways to reduce greenhouse gas emissions and combat global climate change. Replacing older refrigerators with newer ones is potentially one of the most immediate and accessible ways to reduce energy as far as appliances are concerned, for three reasons. First, refrigerators require more energy than almost all other home appliances, as they are always turned on and must keep food at a temperature lower than the surrounding environment (Cavallo and Mapp 2000). In residential homes, refrigerators consume 13.7% of total electricity (EIA 2005). Second, they are very costly and thus consumers usually only replace refrigerators when they stop functioning (Kim *et al.* 2006). Third, replacing requires no behavior change on the part of the consumer, a barrier to other methods of energy efficiency and conservation.

The energy efficiency of refrigerators has been improved greatly in the last two decades due to the National Appliance Energy Conservation Act of 1987 (Hakim and Turiel 1996). Legislation for higher energy efficiency standards took effect for refrigerators in 1990, 1993, and 2001 (Meyers *et al.* 2003) These standards have resulted in better insulation, compressors, fans and motors, heat exchanger surfaces, and generally smarter controls, all of which decrease energy consumption (Kinney and Belshe 2001). More recently, manufacturers strive to ensure that their products receive the Energy Star certification awarded by the federal government to energy efficient appliances (Brown *et al.* 2002, Harris *et al.* 2007). Energy Star products are easy to find and their high energy efficiency standards may increase consumer satisfaction (Moxnes 2004). However, Energy Star certification is not mandatory, and consumers may still choose to purchase cheaper, less efficient appliances (Webber *et al.* 2000, Brown *et al.* 2002). Nevertheless, overall efficiency improvements have been drastic – between 1985 and 2005, average energy consumption by refrigerators was cut almost in half, from 1058 kilowatt-hours per year (kWh/year) to 580 kWh/year (Smit 2006).

Educational programs to increase energy efficiency have been common in recent years. Utility companies, government agencies, private businesses, and nonprofit organizations frequently implement energy efficiency programs, often focused on educating or offering rebates to consumers. In nonprofits and businesses, these programs are voluntarily offered; in utility companies and government they are usually mandated by legislation. Such programs have been quite effective; the best of them as ranked by York and Kushler (2003) saved over 2000 gigawatt-hours each year.

Surprisingly, few refrigerator replacement programs have been attempted, given the substantial energy savings that could be achieved. Since consumers are unlikely to purchase a new refrigerator on their own given the significant upfront cost, replacement programs can be of much benefit. The few programs that were tried largely succeeded. (Kinney and Belshe 2001). The largest was in New York City, which provided over 15,000 government-funded energy efficient refrigerators free of charge to low-income families (Pratt and Miller 1997). Overall, the program saved an average of 578 kWh/year and $39.25/year per refrigerator. Utility-sponsored refrigerator programs for low income households in Southern California found an energy savings value of between 665 and 795 kWh/year/household, resulting in a total of nearly 18 million kWh/year saved (KEMA-XENERGY Inc. and Business Economic Analysis & Research 2003), nearly the entire electricity consumption of the country of Comoros, which has a population of 750,000 (Central Intelligence Agency 2009). Pacific Gas and Electric (PG&E), one of the utilities participating sponsoring a low-income refrigerator replacement program, installed 1,071 refrigerators through December 2008, though data on what effect this had on energy consumption is not yet available (Pacific Gas and Electric Company 2009).

No studies have documented a refrigerator replacement program in a business or university setting. However, the potential for such programs are large, given that refrigerators are so commonly seen in businesses and colleges.

This study assesses the feasibility of a large-scale refrigerator replacement program at the University of California (UC), Berkeley. This program would aim to replace old, energy inefficient refrigerators with Energy Star models that often use 60% less energy (Energy Star 2009). Such a program has not been attempted before at a university campus so the results could be very significant. If my study finds that such a program is feasible at UC Berkeley and the program is successfully implemented, other universities might adopt similar initiatives. This could result in large energy savings, leading to fewer greenhouse gas emissions and less severe climate change.

The way the UC Berkeley administration deals with energy and appliances presents a challenge. In residential homes the people who install the new refrigerator are responsible for paying the upfront cost but also see a monthly monetary benefit in the form of a reduced electric bill. At UC Berkeley, however, departments fund the purchase of new appliances while the university pays the energy bill (Chess 2009, pers. comm.). This disconnect results in an economic disincentive to purchase new appliances – departments don't see any of the benefit in the long run from decreased energy usage, and the University is hesitant to disburse money for something it would normally not be responsible for buying. Therefore, refrigerators are usually only replaced by departments when absolutely necessary, usually when the old one breaks.

There is hope that the University will sponsor a replacement program. The University paid a consulting firm to determine potential projects to increase campus energy efficiency (Newcomb Anderson McCormick, Inc. 2008). Facilities Services, a department responsible for the upkeep of campus buildings, is attempting to fund some of these projects (Chess 2009, pers. comm.). Refrigerator replacements were identified as a possible source of improvement.

Ultimately, this study determines the potential energy and monetary savings of a refrigerator replacement program at UC Berkeley. Specifically, this study examines if the economic disincentive for departments to buy new refrigerators can be overcome through a shared purchase between each department and the University. It also investigates how powerful of an incentive a Green Department Certification would be and discusses how people with control of money think about this issue through analysis of a survey. Finally, it determines average energy consumption of on campus refrigerators through a sample audit. Armed with this information, I determined a realistic payback period for the new refrigerators using a simple economic analysis.

I hypothesize that over half of the refrigerators on campus will be older models and thus that significant energy and, eventually, monetary savings will be possible with replacements. Thus I anticipate that a large-scale refrigerator replacement project will be financially feasible at UC Berkeley – that is, the payback period to the University will be less than 10 years. Though Kim *et al.* (2006) found that the payback period for refrigerators is on average close to 18 years, PG&E, UC Berkeley's energy provider, offers large rebates for projects of this type. This will make the payback period – the amount of time that must pass before the initial cost of the refrigerators is recouped – much lower than otherwise anticipated (Chess 2009, pers. comm.). Refrigerators, while expensive, are less so than in previous years (Greening *et al.* 1997, Ellis *et al.* 2007) and are potentially affordable for the University when energy savings are considered.

I hypothesize that department purveyors will vary widely in how much money they are willing to offer for new refrigerators, with some unwilling to offer any money at all, and some willing to pay for most of the cost, given the potential monetary and environmental benefits. However, I expect most to lie somewhere between these two extremes, with most departments prepared to give about 25% of the total price. I expect environmental incentives to play a small but not negligible role in the willingness to purchase, because environmental issues are presently highly visible, and departments may wish to capitalize on this in order to improve their image with the university and with students.

Methods

This study employed two approaches: a refrigerator energy consumption assessment and a survey of department staff with purchasing authority.

Study Population I examined on campus refrigerators at UC Berkeley. I looked for departmental and office-owned refrigerators which are primarily used for food storage for faculty, staff, and graduate students. I did not look at personal, compact refrigerators used in personal offices, because such refrigerators are not purchased by departments and would not be eligible for replacement. I also ignored laboratory refrigerators used to store scientific material such as biological samples, since they are often inaccessible and can be more expensive to replace. Finally, I did not consider industrial-sized refrigerators usually used for storing food for food service locations such as campus cafés.

These omissions will likely lead to an underestimation of overall energy consumption as well as potential energy savings should a replacement program attempt to cover these. It seems unlikely that the University will attempt to replace personal refrigerators, but more likely that it will cover laboratory refrigerators (Chess 2009, pers. comm.).

There are approximately 80 buildings are on campus, each with different uses and sizes. Some buildings have many refrigerators due to the abundance of laboratories and break rooms. Others, like administrative buildings, tend to have many personal, compact refrigerators. Some buildings have a break room with a full size refrigerator on every floor; others are composed mostly of classrooms and have very few refrigerators.

Ideally, I would have picked from a random sample of all refrigerators on campus, but this is impossible since no data on campus refrigerator locations existed before this study. Instead, I conducted a full audit of eight on campus buildings, wherein I found 85 total refrigerators. Buildings were chosen both for convenience and to capture a variety of departments and uses. Departments that my audit covered include Environmental Science, Policy, and Management, Psychology, Bioengineering, Mechanical Engineering, and Social Welfare. Some buildings were used mainly for classrooms, others contained many laboratories, and still others housed administration.

Data Collection To ensure an accurate audit of refrigerators in each building, I went through each one floor by floor. To find refrigerator locations, I went to department offices and asked staff where refrigerators were. In most cases people knew rooms with refrigerators on that floor or referred me to someone who did. I recorded the brand and model number of each refrigerator I found.

I looked up the model numbers in databases (Kouba-Cavallo Associates 2008, California Energy Commission 2009, Department of Energy 2003, Federal Trade Commission 2008) that link them to energy usage in kWh/year. Miller and Pratt (1998) found that refrigerators consume more energy as they age, and suggest a degradation factor of 1.37% per year, which I used in my analysis.

I took this approach because it is the most efficient way to gather energy consumption data for a large sample size. A far more accurate approach is to directly metering refrigerators. I chose not to use this approach for two reasons. Firstly, an accurate reading for one refrigerator takes at least several hours to obtain. Secondly, the largest variable that affects energy usage among the same model of refrigerator is the temperature of the room it is in (Masjuki et al 2000). The energy consumption data I would obtain for metering would likely catch more of this than any other variable. However, temperature does not matter for the purposes of this study since replacement refrigerators would be placed in the same buildings, with the same average temperatures. Since I was not equipped with a thermostat to control for this, the metered data for a large group of refrigerators would not be substantially better than that obtained from the databases, such as the Department of Energy (DOE) test results database. This logic is echoed by Meier (1995: page 238), who says that “the DOE test is a reasonably good predictor of field consumption of a group of units where individual variations in condition offset each other.”

Data Analysis I only analyzed pre-2002 refrigerators for which I was successfully able to match the model number to year and energy consumption. I chose the year 2001 as the cutoff because new federal energy efficiency standards that took effect that year, and because Newcomb Anderson McCormick, Inc. (2008) used that year. Refrigerators after that point use less energy and savings will not likely be sufficient to make the investment worthwhile. Additionally, Kim *et al*. (2006) found that in order to minimize global warming potential, refrigerators should be replaced every 2-11 years, and a replacement project in 2009 or 2010 falls inside this range.

Using the current price of energy for the University, \$0.10/kWh (McNeilly 2009, pers. comm.), and projected future prices of energy, derived from a regression analysis of an electricity prices database for California (Energy Information Administration 2009), I calculated the total energy use and cost of operating the refrigerators for ten years. Then I repeated the analysis assuming the refrigerators were replaced with more energy efficient models of an equivalent size. I used a discount rate of six percent, as determined by Ahmed (2007), using the equation Net Present Value = C(1/{1+D})^T, where C is cost, D is the discount rate, and T is the number of years. I did this for each year for ten years of energy consumption. I incorporated the likely purchase prices and energy consumption of the new refrigerators (Damm 2009, pers. comm., Energy Star 2009) as well as the rebate available from PG&E, which, as a special deal for the University, is anticipated to be \$538 for a standard size refrigerator, assumed to be 25 cubic feet (Newcomb Anderson McCormick, Inc. 2008). Using this \$538 per 25 cubic feet ratio, I calculated the likely rebate for refrigerators of different sizes. Taking all of these values into consideration, I calculated a simple payback period (simply the purchase price of the new refrigerator divided by the average yearly monetary savings) which reveals how many years of using the new refrigerators it will take for the energy savings to be financially worth the initial costs. Using the amount of energy saved I also calculated how much less carbon dioxide (CO2) will be emitted yearly based on the energy mix that the University uses, which results in 0.292 kilograms CO2/kWh (Ahmed 2007). This result is obtained by multiplying this figure by the total kWh saved. Finally, I calculated how long it would take to get an environmental benefit, by assuming the refrigerators were composed of 67% metals, 28% plastics, and 5% glass, as noted by Kim *et al.* (2006), and using the associated global warming potential of these materials (Quirk 2009, pers. comm.).

Survey The survey population consisted of all current University staff who had authority over processing unit identification for their department and were therefore capable of making purchasing decisions. To determine survey questions I completed five preliminary interviews with department purveyors after gaining approval from the Committee for Protection of Human Subjects. I engineered my questions to see how to best determine environmental awareness and willingness to pay. Refer to Appendix 1 for survey questions.

Survey results are discussed in terms of what the average department purveyor thinks. For the questions with a quantitative ranking component, an average, median, and mode were calculated. These results will inform my discussion and can be presented to the University as an option beyond PG&E rebates for defraying the costs of the project.

Results

Refrigerator Audit Results I surveyed eight buildings, finding a total of 85 refrigerators, 22 of which, or 26%, were manufactured before 2002. For the 19 of these I found data for, the average energy consumption was 630 kWh/year.

Table 1. Energy and emissions data for old refrigerators and the new ones assumed to replace them.

Average energy consumption of old refrigerators over 10 years	Average CO2 emissions over 10 years for old refrigerators	Average energy consumption of assumed replacements	Average CO2 emissions over 10 years for new refrigerators	Difference in average energy consumption	Difference in CO2 emissions
655 kWh/year	191 kg CO2/year	340 kWh/year	99 kg CO2/year	315 kWh/year	92 kg CO2/year

Assumed replacement refrigerators averaged 10.9 cubic feet and 81 kg, of which 54.27 kg are metals, 22.68 kg are plastics, and 4.05 kg is glass. Using global warming potential data from Ian Quirk (2009, pers. comm.), each refrigerator requires, on average, 774 kg CO2 to manufacture. With energy savings of 92 kg CO_2/year, replacements are environmentally friendly after 8.4 years.

Table 2. Average payback periods for the University for refrigerators under a replacement program. Subsidies come in the form of a PG&E rebate and department compensation.

Subsidy Offered	No Subsidy	PG&E Rebate Only	PG&E Rebate and 25% Department Subsidy	PG&E Rebate and 50% Department Subsidy
Payback Period	19.6 years	8.1 years	6.1 years	4.1 years

Financial benefits after the payback period are $31.50/year/refrigerator.

It is useful to extrapolate data from my refrigerator audit to the entire university. I found an average of 10.6 refrigerators per building. In a campus of 81 buildings, this corresponds to 858 total refrigerators. Of those audited, I found that about 26% of campus refrigerators were old enough to be eligible under a replacement program, or 223 for the whole campus. If all of these were to be replaced, it follows (using 315 kWh/refrigerator/year and 92 kg CO_2/refrigerator/year as calculated above) that the campus could save 70,245 kWh and 20.5 tons of CO_2 every year.

Survey Results Three hundred and eighteen people, one from each department on campus, were emailed and asked to take the survey. Only 46, or about 14%, responded. Forty-four of these 46, or 96%, had influence over purchases of appliances. The average number of years respondents worked in their department was 10.8 with a standard deviation of 9.9.

Overall environmental concern was relatively high, with a 3.4 average on a scale from 1 (minimum) to 4 (maximum). The median and mode were both 4. Similarly, the offer of an environmental reward for replacing refrigerators was also high, with a 2.9 average, a median of 3, and a mode of 4. 32.6% of respondents requested more information on how to make their department more environmentally friendly.

Different features were of variable importance to survey respondents, as shown in Fig. 1.

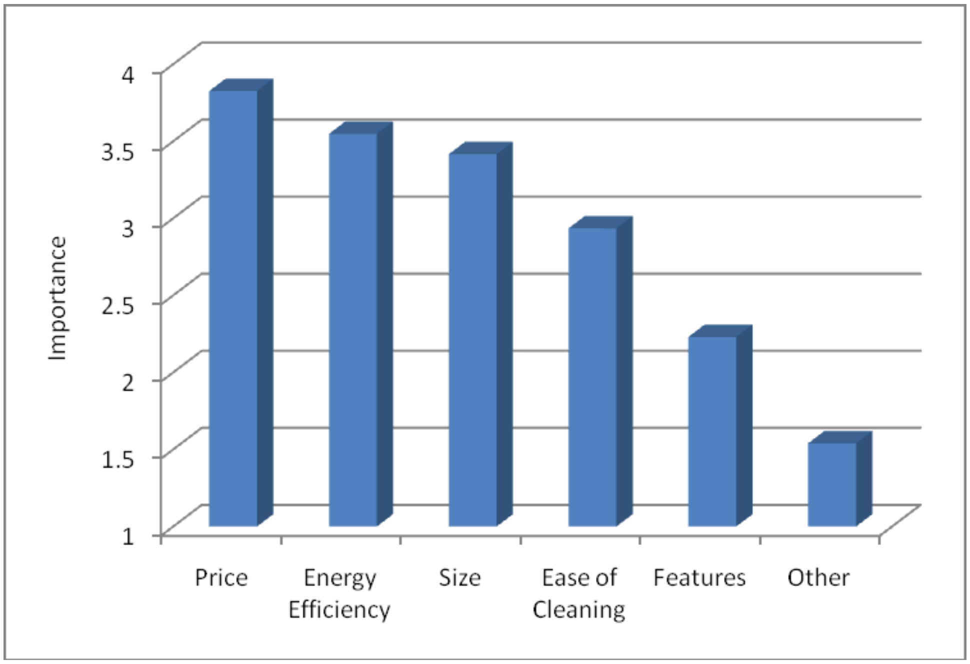

Figure 1. Facets of refrigerators that were important to buyers; with 4 being very important and 1 being of no importance. Features of importance to respondents included a large freezer compartment, ice trays, self-defrosting, and shelf arrangement. "Other" included such factors as reliability, a long lifetime, and aesthetics. However, the responses for "other" seemed to be indicate that respondents were confused, and the value may be too high.

Most respondents (89%) did not have any refrigerator purchases planned.

Subsidies were important to respondents. 74% would replace their refrigerators if they only had to pay for 50% of the refrigerator, 80% if they only had to pay 25%, and 96% if it was free.

Discussion

I found that the environmental payback period for a replacement project would be 8.4 years and the financial payback period with the PG&E rebate, but without department support, would be 8.1 years. Given that the payback period without any subsidies is 19.6 years, 8.1 years is short enough to be readily acceptable to the University.

The financial payback periods were close to what I expected, but only because I initially underestimated the size of the PG&E rebate. Without a rebate of this size, the payback periods would be much higher than I hypothesized. Partly this is because UC Berkeley pays a lower energy price of $0.1/kWh than the rest of California: $0.144/kWh is the residential statewide average for 2007 (Energy Information Administration 2009), and partly because the refrigerators were not as old as I expected. The payback period of 19.7 years is similar to that found by Kim *et al.* (2006). Subsidies from PG&E and from departments push this number downward, though a 50% subsidy is required to have a more financially viable payback period of 10 years.

My hypothesis overstated the population of refrigerators eligible for replacement: given that there is no financial incentive to replace appliances, I expected over half to be old enough to replace. This has not been the case, possibly because campus refrigerators are used more frequently by more people than residential refrigerators. Thus they are likely to experience more wear and tear and require more frequent replacement.

Compared to an estimated 212,827,845 kWh consumed and 209,000 tons of CO2 emitted yearly campus-wide (Ahmed 2007), the 20.5 tons of CO2 that a refrigerator replacement program would save is only 0.01% of emissions, but would likely come at a lower cost than other methods to reduce energy consumption.

Survey The survey results fit my hypotheses that a significant monetary incentive would have to be offered before participation in the replacement program would reach a meaningful level. 74% of respondents would accept a 50% subsidy. Combined with the PG&E rebate, costs to the University could be reduced to as low as 30% of the purchase price, resulting in a very short six year payback period for the University.

Willingness to pay for replacement refrigerators likely varied due to each department's unique financial situation as well as the number of refrigerators they have and how many people use each one. This seems plausible, considering that similar studies, in particular Wood *et al.* (1995), have found that willingness to pay for environmental quality improvements varied widely from person to person.

It was interesting to note, however, that 4% of respondents would not replace their refrigerator even if it was for free. This is probably because of the hassle involved: installation would require moving the old refrigerator's contents to a temporary location before putting in the new one, and the installation could take hours, especially for multiple refrigerators. The University would have to work around this somehow if they attempt to replace all eligible refrigerators.

Price, energy efficiency, and size were the most important factors in refrigerator purchases. Since these factors are also most important to the University, there will likely be little conflict on which models can be purchased.

The results do not support my hypothesis that environmental concerns do not factor very much into willingness-to-pay. I was surprised to find that the Green Department Certification would be a powerful incentive, 2.9 on a scale from 1 to 4. The results here likely suffer from a response bias – people who are concerned with the environment are more likely to fill out the survey in the first place. This response bias most likely also comes into play for the question that asks what overall environmental concern was (3.4/4) and for the importance of energy efficiency in refrigerators (3.5/4)

Limitations I have assumed that my sample size of both refrigerators and department purveyors is an accurate reflection of reality. Additionally, I will be assuming that individual uses of each refrigerator will not change after its replacement. This is an important assumption, because changes in use can affect energy consumption greatly (Masjuki et al 2000) and could be a large confounding variable. Many of the numbers I have assumed for my analysis, such as energy prices, the deterioration factor for increasing energy consumption as refrigerators age, the discount rate, and the global warming potential for refrigerators and electricity, are uncertain and influence the results highly. Finally, I did not account for refrigerator size – in my audit, I found that most refrigerators were not fully stocked, and many were less than half full. A replacement program could acknowledge this and reduce the size of the replacements, which would result in a lower payback period and less carbon emissions, since larger refrigerators consume much more energy than smaller ones (Harris *et al.* 2007).

Conclusions This study is unique in its treatment of refrigerators at a university. Nevertheless, comparisons between the potential for a replacement program at UC Berkeley can be compared to that attempted by others. New York City's program saved 263 kWh/year/refrigerator more than I predict UC Berkeley's will (Pratt and Miller 1997). Utility-sponsored programs in California saved over 385 kWh/year/refrigerator (KEMA-XENERGY Inc. and Business Economic Analysis & Research 2003) and 440 kWh/year/refrigerator (West Hill Energy and Computing, Inc. 2008) more than my results show. The increased savings may be because energy efficiency improvements in the 1980's and mid 1990's were faster and more significant than savings later than that.

Other universities could find my results applicable to their own situation and attempt a program of their own. However, more research should be conducted at other universities, both large and small, to see if the results of this study are still applicable. Particularly interesting would be the study population – does UC Berkeley have more or less refrigerators for its size than other universities, and are its refrigerators older or newer? Is the financial situation of other universities better or worse, and how does this affect departmental willingness-to-pay? How would energy consumption and department structuring affect the finances? In most cases, universities, as large consumers, do get charged lower prices for energy than the prevailing rate in their area. It is also usually the case that the university administration pays for the energy bill whereas departments pay for their appliances (Chess 2009, pers. comm.).

It is likely that other universities in the United States would face shorter payback periods, because electricity prices are generally higher in California (Energy Information Administration 2009). However, utility companies in California offer more rebates than in other states. As previously noted, UC Berkeley has many discounts available – a large rebate from PG&E as well as a good deal for purchasing refrigerators in bulk. If such discounts are not available for other universities, refrigerator replacement may not be as viable. However replacements in other states could also abate much more carbon dioxide, because the energy mix in California is among the most environmentally friendly in the nation.

Similar research could also be done for small and large business settings. The issues facing businesses are likely to be different – refrigerators may be used more or less often and for different purposes, and businesses are probably less likely to have the political will to implement a replacement program because it would take so long to improve the bottom line. On the other hand, the recent trend in businesses becoming more environmentally friendly to attract customers may counteract this (Kirchhoff 2000). Finally, refrigerators are one among many appliances that have gotten more efficient over time. Research on office machines and heating and cooling systems could show the potential for large energy savings as well.

This study has shown that a refrigerator replacement program at UC Berkeley could potentially save large amounts of energy and, given the right incentives, is likely to be financially feasible. Additionally, implementing the program should prove to be relatively straightforward once funding is secured. Energy Star refrigerators are readily available for purchase from many suppliers, and the University can purchase them in bulk to provide to departments.

Ultimately, a refrigerator replacement program is up to the will and the funding of the University. UC Berkeley has adopted a policy that greenhouse gas emissions should be reduced to 1990 levels by 2014 (Newcomb Anderson McCormick, Inc. 2008), and this study has shown that refrigerator replacements could be a financially viable way to reduce emissions. Given California's and UC Berkeley's reputation for environmental leadership, and the interest that the University has shown in my research, a replacement program could very well happen soon.

References Cited

Ahmed, Fahmida. 2007. Feasibility Study 2006-2007 Final Report. Unpublished report for UC Berkeley Climate Action Partnership. 139 pp.

Brown, R., C. Webber, and J. G. Koomey. 2002. Status and future directions of the Energy Star program. Energy 27: 505-520.

California Energy Commission. 2009. Appliances Database – Refrigeration. http://www.energy.ca.gov/appliances/database/excel_based_files/Refrigeration/, accessed January 31, 2009.

Calwell, C., and T. Reeder. 2001. Out with the Old, In with the New: Why Refrigerator and Room Air Conditioner Programs Should Target Replacement to Maximize Energy Savings. Natural Resources Defense Council. 37 pp.

Cavallo, James and James Mapp. 2000. Targeting Refrigerators for Repair and Replacement. Unpublished report for Proceedings of the 2000 ACEEE Summer Study on Energy Efficiency in Buildings. Washington, DC.: American Council for an Energy-Efficient Economy. 8pp.

Chess, Judy. Principal Planner for the Physical and Environmental Planning Unit in Capital Projects, UC Berkeley, Berkeley, California. 2009, personal communication.

Central Intelligence Agency. 2009. The World Factbook. https://www.cia.gov/library/publications/the-world-factbook/rankorder/2042rank.html, accessed May 2, 2009.

Damm, Nimfa. Card Program Manager, Business Services – Procurement, UC Berkeley, Berkeley, California. 2009, personal communication.

Department of Energy. 2003. Refrigerator Energy Use Data. http://www.waptac.org/sp.asp?id=70#refrigdata.htm, accessed January 31, 2009.

Ellis, M, N Jollands, L Harrington, A Meier. 2007. Do energy efficient appliances cost more? Proceedings of the ECEEE 2007 Conference. 10 pp.

Energy Information Administration. 2005. U.S. Household Electricity Charts: A/C, Heating, Appliances. http://www.eia.doe.gov/emeu/reps/enduse/er01_us_figs.html#3, accessed May 1, 2009.

Energy Information Administration. 2009. 1990 - 2007 Average Price by State by Provider (EIA-861). http://www.eia.doe.gov/cneaf/electricity/epa/epa_sprdshts.html, accessed April 5, 2009.

Energy Star. 2009. Refrigerators and Freezers for Consumers. http://www.energystar.gov/index.cfm?c=refrig.pr_refrigerators, accessed February 1, 2009.

Greening, Lorna A., Alan H. Sanstad and James E. McMahon. 1997. Effects of Appliance Standards on Product Price and Attributes: An Hedonic Pricing Model. Journal of Regulatory Economics 11: 181-194.

Federal Trade Commission. 2008. Appliance Energy Database – Refrigerators and Freezers. http://www.ftc.gov/bcp/conline/edcams/eande/appliances/fridge.htm, accessed January 31, 2009.

Hakim, S. H. and I. Turiel. 1996. Cost-efficiency analysis in support of the energy conservation standards for refrigerator/freezers. ASHRAE Trans 102: 247–257.

Harris, J., Payne, C., Diamond, R. Blumstein, C., Iyer, M., and S. Hans-Paul. 2007. Toward a Sustainable Energy Balance: Progressive Efficiency and the Return of Energy Conservation. University of California Energy Institute, Center for the Study of Energy Markets. 23 pp.

KEMA-XENERGY Inc. and Business Economic Analysis & Research. 2003. Impact Evaluation of the 2001 Statewide low-income energy efficiency (LIEE) Program. Unpublished report for Southern California Edison Company, Southern California Gas Company, San Diego Gas & Electric Company, and Pacific Gas and Electric Company. 110 pp.

Kim, H. C., Keoleian, G. A., and Y. A. Horie. 2006. Optimal household refrigerator replacement policy for life cycle energy, greenhouse gas emissions, and cost. Energy Policy 34: 2310-2323.

Kinney, L. and R. Belshe. 2001. Refrigerator Replacement in the Weatherization Program: Putting a Chill on Energy Waste. The Weatherization Assistance Program. 36 pp.

Kirchhoff, S. 2000. Green Business and Blue Angels. Environmental and Resource Economics 15: 403-420.

Kouba-Cavallo Associates. 2008. Refrigerator and Freezer Energy Rating Database. http://www.kouba-cavallo.com/refmods.htm, accessed April 1, 2009.

Masjuki, H., H. Saidur, R. Choudry and T.M.I. Mahlia. 2000. Factors effecting energy consumption of household refrigerator-freezers. Tefcon 2000 Proceedings 2: 92-96.

McNeilly, Lisa. Director of Sustainability, UC Berkeley, Berkeley, California. 2009, personal communication.

Meier, Alan. 1995. Refrigerator use in the laboratory and in the field. Energy and Buildings 22: 233-243.

Meyers, S., McMahon, J.E., McNeil, M., and X. Liu. 2003. Impacts of US federal energy efficiency standards for residential appliances. Energy 28: 755-767.

Miller, J.D. and R.G. Pratt. 1998. Estimates of Refrigerator Loads in Public Housing Based on Metered Consumption Data. Prepared for the U.S. Department of Energy. 93 pp.

Moxnes, E. 2004. Estimating customer utility of energy efficiency standards for refrigerators. Journal of Economic Psychology 25:707-724.

Newcomb Anderson McCormick, Inc. 2008. UC Strategic Energy Plan. Prepared for University of California Office of the President. 546 pp.

Pacific Gas and Electric Company. 2009. PG&E Low Income Programs Monthly Report for December 2008. Unpublished report for Sarita Sarvate of the California Public Utilities Commission. 6 pp.

Pratt, R. and J. Miller. 1997. The New York Power Authority's Energy-Efficient Refrigerator Program for the New York City Housing Authority - Savings Evaluation. The Office of Energy Efficiency and Renewable Energy and the U.S. Department of Energy. New York. 89 pp.

Quirk, Ian. Undergraduate Student, UC Berkeley, Berkeley, California. 2009, personal communication.

Smit, Kevin L. 2006. 2005 Refrigerator/Freezer Recycling Program Evaluation. Snohomish County Public Utility District No. 1. 9 pp.

Webber, C. A., R.E. Brown, J.G. Koomey. 2000. Savings estimates for the Energy Star voluntary labeling program. Energy Policy 28: 1137-1149.

Wood, Lisa L., Anne E. Kenyon, William H. Desvousges, and Lyn K. Morander. 1995. How much are customers willing to pay for improvements in health and environmental quality?. The Electricity Journal 8: 70-77.

West Hill Energy and Computing, Inc.. 2008. Impact evaluation of the 2005 California low income energy efficiency program. Unpublished report for Southern California Edison Company. 168 pp.

York, D. and M. Kushler. 2003. America’s best: profiles of America’s leading energy efficiency programs. Report for the American Council for an Energy-Efficient Economy. 17 pp.

Acknowledgements

I am grateful to my mentor, Dan Kammen, for his valuable input to my project, as well as referring me to many helpful contacts. I received great advice on my methodology from Jim Mapp, Reuben Deumling, Chris Jones, Asa Hopkins, Jim Lutz, and Alan Meier. Robin Turner, Gabrielle Wong-Parodi, and Ian Quirk were instrumental for their help in reviewing my writing. My contacts at the University were invaluable, especially Judy Chess, Nimfa Damm, and Lisa McNeilly. Janis Honda, Michelle Wong, and Alex Valenti provided me with data for University Hall.

Appendix 1 – Survey Questions

Email introduction to survey The Department of Procurement Services is working with Ryan Dash – an undergraduate student conducting an anonymous survey on a refrigerator replacement project in cooperation with Capital Projects and the Office of Sustainability. He will be using the results of this survey in his senior thesis research. Your response would be very much appreciated.

Your responses will also help in the design of a new program to reduce the energy used in campus refrigerators. Replacing old refrigerators with newer, energy efficient ones can save up to 40% on electricity bills and can also reduce greenhouse gas emissions by up to one ton per refrigerator. This program is part of the campus Strategic Energy Plan, and will help us meet our target of reducing greenhouse gas emissions to 1990 levels by 2014.

This survey should only take 5-10 minutes of your time. We hope that you will take the time to respond.

Please start your survey by clicking on the link provided below.

Introduction to survey in web page The University is considering the implementation of a replacement project for on campus refrigerators to reduce energy consumption. Each refrigerator replacement may yield up to a ton of greenhouse gas emission reduction, contributing to the reductions goal set by the campus (calcap.berkeley.edu). The University will likely subsidize some, but not all, of the cost of these refrigerators.

1. Please select your role relevant to the purchase of appliances in your department.

a. I “approve” the purchase of kitchen appliances for my department

b. I can “influence” the decision to purchase or not to purchase kitchen appliances for my department

c. I do not have a role to make a decision and cannot influence the purchase of kitchen appliances for my department *d. Not Applicable - I have retired from the University/No longer employed at UC Berkeley*

2. How many years have you been working in your department?

Answered in a text box

3. If you participate in the program your department may receive recognition from the University as being environmentally friendly. This may take more than one form, including being part of the process to achieve a Green Department Certification. How much would this influence your willingness to purchase energy efficient refrigerators for your department? Please rank this from 1 to 4, where 1 is no influence at all and 4 is very influential.

a. 1

b. 2

c. 3

d. 4

4. What department do you work in?

Answered in a text box

5. If the purchasing authority is shared or delegated within your unit, how is this authority split between you and others?

Answered in a text box

6. In general, how much weight does your department give to environmental concerns in making purchasing decisions? These concerns could include energy use, emissions reduction, and waste reduction.

a. Not Important

b. Somewhat Important

c. Important

d. Very Important

7. What factors are important for your department's new refrigerator? Rank each of these factors as not important, somewhat important, important, or very important.

i. Size/Capacity: *not important, somewhat important, important, very important*

ii. Energy Efficiency: *not important, somewhat important, important, very important*

iii. Cost: *not important, somewhat important, important, very important*

iv. Ease of Cleaning: *not important, somewhat important, important, very important*

v. Other: *not important, somewhat important, important, very important*

8. If you marked features as being important to you, which features are you referring to?

Answered in a text box.

Describe what other factors are important, if any.

Answered in a text box.

9. Do you currently have any refrigerator purchases planned for this year?

a. Yes

b. No

If yes, how many potential refrigerators and for what reason? *Answered in a text box.*

If no, why not? *Answered in a text box.*

10. Would you like more information about saving energy and making your department more environmentally friendly? If you answer "yes" please provide your information below so we can provide you with the relevant information on becoming a "Green Department."

a. Yes

b. No