Final Report

Product Trends and Manufacturer Insights for Residential Laundry, Cooking, and Refrigeration Appliances

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1. Introduction

This report summarizes findings from Research Into Action's market characterization research to inform the California Investor Owned Utilities' (IOUs) Statewide Plug Load & Appliances program (PLA) team. The report's findings provide a snapshot of market conditions for three high-touch appliance categories: laundry appliances (clothes washers, often sold accompanied by clothes dryers); refrigerators; and residential cooking products such as ranges, stoves, ovens, and microwaves. We have organized this report into four primary chapters: an overarching discussion of appliance efficiency trends along with individual chapters summarizing our research on laundry products (clothes washers and dryers), residential cooking products, and refrigerators. For convenience, the report also includes four appendices describing additional research (submitted previously as individual memos) to support the PLA team's product planning and work paper update efforts.

2. Methods

To conduct a market characterization of these high-touch appliances, we engaged in two research activities: a review of secondary data sources and in-depth interviews with appliance manufacturers and U.S. Environmental Protection Agency (EPA) ENERGY STAR® staff. The manufacturers who completed interviews represented five companies which together accounted for more than 70% of the US appliance market share in 2013 (Appliance Magazine 2014a). Research topics included:

- Penetration of energy efficient units, their sales, and installed base
- Non-energy benefits of efficient appliances
- Market failures
- Supply-side structure and supply channels
- Consumer behavior
- Energy efficient specifications and updates

The team also explored several product-specific research questions identified by the PLA team.

- **Clothes Washers**: Understand energy differences between top- and front-loading configurations and explore opportunities for washer-dryer pairing.
- **Refrigerators**: Identify emerging energy savings opportunities, including component level opportunities, such as the feasibility of a campaign for efficient compressors similar to the *Intel Inside* campaign.

- **Microwaves and Stove Top Ovens**: Explore the potential for an energy efficiency program for this product category in advance of the upcoming federal specification changes.

2.1. Secondary Data Review

We reviewed secondary sources to learn about technical energy-savings opportunities, market penetration, energy-efficiency specifications, non-energy benefits, and consumer behavior. In particular, we reviewed:

- Federal efficiency rule-making documents and Technical Standard Documents
- Recent conference proceedings
- ENERGY STAR shipment data and product specification documents
- Federal and California databases on market penetration (e.g., California Lighting and Appliance Saturation Study (CLASS) and Residential Energy Consumption Survey (RECS))
- Studies on non-energy benefits, consumer behavior, and program implementation
- California IOU work papers

2.2. Primary Data Collection

We collected primary data on ENERGY STAR-certified appliance availability by visiting retailer websites and recording the number of models available in California stores. The team also conducted in-depth interviews with five manufacturers and with EPA ENERGY STAR staff. We contacted six manufacturing companies and obtained interviews with five representatives of white good manufacturers plus representatives from the ENERGY STAR appliances team. The roles of the interviewees were:

- Analyst, Regulatory Affairs
- Director, Environmental Sustainability/Green Leadership
- Corporate Regulatory/Environmental Affairs Manager
- Global Product Stewardship Manager, Regulatory Counsel
- Energy Efficiency Consultant
- ENERGY STAR Appliances Program Manager

During interviews, we covered each of the three major product categories in this report and discussed topics pertaining to:

- Manufacturer views and preferences related to efficiency program design and delivery

- Future product and market trends
- Opportunities to increase product efficiency (such as energy-saving components)
- Price points at which ENERGY STAR sales are lagging
- Clothes washer and dryer pairing
- The energy-saving potential in smart or connected appliances
- Efficient product market penetration

We analyzed interview responses, including identifying and coding crosscutting themes, using the *NVivo* qualitative data analysis software.

3. Overarching Trends

Through our interviews with manufacturers and ENERGY STAR representatives, we have identified several cross-cutting appliance trends.

3.1. Energy Savings Potential

Clothes washer efficiency has been increasing steadily, while refrigerator efficiency has remained largely stable (Figure 3-1). Consistent with these trends in energy use, between 2008 and 2016, EPA has revised the ENERGY STAR specification for clothes washers more frequently than the specification for refrigerators. EPA recently revised the refrigerator specification in response to a new federal efficiency standard taking effect. The ENERGY STAR specification in effect prior to that revision had been in place for more than six years. In contrast, DOE has revised the ENERGY STAR clothes washer specification every two-to-four years.

Figure 3-1: ENERGY STAR Specification Development Timeline

[a] Top-mounted refrigerator-freezers with automatic defrost and without an automatic icemaker, 20.8-21.1 cubic feet.

[b] Front-loading, >2.5 cubic feet.

[c] With the Version 7.1 clothes washer specification, ENERGY STAR adopted the Integrated Modified Energy Factor (IMEF) as a metric. IMEF differs from the Modified Energy Factor (MEF) metric used in previous versions in that it accounts for energy use in low-power modes while MEF reflected active-mode power use only.

[d] The ENERGY STAR Version 6.1 specification for clothes washers included updates for commercial washers only; the specification for residential washers was retained from Version 5.0.

[e] Standard-sized, electric dryers without connected functionality.

This graphic excludes cooking products because they have no ENERGY STAR specifications and minimal federal codes.

Industry sources see the greatest potential for energy savings in product categories that have not historically been subject to efficiency regulations and voluntary standards. In some of these categories, new technologies are generating significant efficiency gains over traditional product designs. In particular, manufacturers cited heat pump clothes dryers and induction cooktops as technologies that could lead to significant reductions in energy use in the next few years. According to one manufacturer, "It would be those types of newer products coming into the regulatory framework…where they would still have runway in terms of working their way through the energy efficiency improvement cycle." In contrast, manufacturers reported that categories with a history of regulations and voluntary standards like refrigerators had largely achieved their energy savings potential and any additional efficiency gains are likely to be incremental. EPA supported this assertion in its announcement of the 2014 Emerging Technology Award for Advanced Clothes Dryers, saying "Advanced clothes dryers present a significant savings opportunity compared to other appliance categories where cost-effective energy efficiency gains have largely been realized" (ENERGY STAR 2013a, 2014a).

Changes in refrigerant can increase the efficiency of a growing range of home appliances as water heaters and clothes dryers incorporate heat pump technologies. Heat pump water heaters and clothes dryers currently use traditional refrigerants. EPA ENERGY STAR staff reported they anticipate efficiency gains from the use of alternate refrigerants, as these refrigerants are developed for heat pumps generally and incorporated into appliances using heat pump technology. EPA's Significant New Alternative Policy program reviews the safety and environmental impacts of refrigerants proposed to replace those being phased out because of their ozone depleting properties.

3.2. Industry Actor Views on Collaboration with Efficiency Programs

Manufacturers expressed a desire for greater advance knowledge of, and consultation around, upcoming efficiency program efforts related to appliances in order to focus their own research and development efforts on technologies likely to be the target of future efficiency programs. For example, manufacturers noted they would be more likely to dedicate substantial R&D efforts to smart grid connectivity if they knew future rebate programs were likely to target this area. The interviewed manufacturers differed regarding the most effective platform for this coordination. One suggested that manufacturers could assign a point of contact to manage relationships with utilities directly. Others suggested utility organizations like Southwest Energy Efficiency Project (SWEEP), Northeast Energy Efficiency Partnerships (NEEP), or Western Regional Utility Network (WRUN), or industry organizations like the Association of Home Appliance Manufacturers (AHAM) would be more effective in facilitating this coordination.

Providing advanced knowledge of upcoming specifications would likely be difficult for program administrators to implement. To drive energy efficiency, program specifications must strike a balance: too lenient specifications run the risk of failing to differentiate the most efficient options as they capture too wide a range of products; too stringent specifications run the risk that market actors will dismiss them as irrelevant as they capture too narrow a range of products. The further into the future efficiency programs forecast, the more difficult it becomes to define specifications that strike this balance. Similarly, the incentive levels program administrators can offer respond to a variety of changing market factors that are difficult to predict into the future, including the product's baseline energy use and energy costs.

Nevertheless, the comments by the appliance manufacturers interviewed for this study expressing a desire for more advance knowledge and collaboration around program design are consistent with findings from consumer electronics program evaluations (Research Into Action and Apex Analytics 2015). These comments indicate that efficiency programs are an important manufacturing consideration in product design, and reflect an increasing desire for cooperation that may be an opportunity for program administrators to explore new program delivery models.

Component-focused program efforts are not appealing to manufacturers. Appliance efficiency programs have traditionally rewarded minimum levels of efficiency for the device as a whole. These programs often leverage specifications like ENERGY STAR and CEE tiers that are based on device-level metrics like unit energy consumption and modified energy factor. However, as baseline appliance efficiency has increased, some program administrators have considered shifting to a program focus on specific components as a potentially more cost effective way to promote appliance efficiency.

Manufacturers stated that more traditional program approaches focused on efficiency at the device level will be more effective than incentives focused on installation of specific components. The interviewed manufacturers cited four reasons for this preference:

- **The pace of introduction of new technologies and new products has increased** as more electronics manufacturers have entered the white goods industry. The components used in each product may change from year to year and the specific components that a program chooses to incentivize may quickly become obsolete.
- **Changes to one component require redesigning other aspects of the appliance.** Manufacturers reported this was particularly the case with clothes washers and refrigerators saying, "When you tweak one thing, you end up tweaking them all."
- **Manufacturers prefer performance standards to be consolidated and coordinated.** In particular, manufacturers cited challenges around discrepancies between Consortium for Energy Efficiency (CEE) Tiers and ENERGY STAR specifications. Manufacturers stated that multiple standards make product design decisions and coordination with retailers more complex and may cause confusion for consumers.
- **Influencing product design at the component level requires coordination on standards and incentives well in advance.** Manufacturers engage in component and technology design between three and five years before a product reaches the market. To motivate manufacturers to install specific components, utility programs must negotiate specifications and incentives in this time frame so manufacturers have sufficient time to incorporate the technology and ensure its viability in the marketplace.

3.3. Consumer Perceptions of Efficiency

Interview findings suggest manufacturers perceive a rejection of efficient appliances among some customers. According to one manufacturer, "If you say it's ENERGY STAR, consumers think, 'oh no, I don't want that. It won't give me the high-performance I need'." As a result, manufacturers have included features in some products that may counteract energy saving technologies. For example, one manufacturer included a switch on efficient clothes washer models that allowed the consumer to override the high-efficiency features of the washer and completely fill the drum with water. Another manufacturer reported designing efficient clothes washers that look like older, less efficient models "because consumers think they do the best job in terms of cleaning performance." Similarly, manufacturers have incorporated resistance heating along with heat pump technology into hybrid heat pump dryers, allowing customers to bypass efficiency in favor of clothes drying speed. Recognizing these challenges, EPA staff reported that ENERGY STAR is preparing messaging to encourage consumers to use their washers efficiently. There may be an opportunity for program administrators to support these efforts with their own consumer education campaigns, which may further benefit from additional consumer research to understand the magnitude and nature of the problem.

3.4. Energy Savings Potential at Lower Price Points

For many appliances, ENERGY STAR penetration is much lower at low price points than at high ones. For example, while 93% of all clothes washers were ENERGY STAR certified in 2014, only 25% of the models priced below $500 were certified. Similarly, only 36% of refrigerators and freezers priced below $600 were ENERGY STAR certified, while 83% of all products in the category were certified.

With few features, it is difficult for manufacturers to justify the higher costs necessary to make low price appliance models energy efficient. Interview findings suggest manufacturers design low end appliance models for customers who want basic functionality at a low price. Without more advanced features, there is little to differentiate one manufacturer's low end models from another manufacturer's low end models, and price becomes more important in driving sales. One manufacturer stated that the lowest-priced ENERGY STAR appliances are "considered a bulk item from the [retailer's] perspective." As such, retailers prioritize assorting the products that will sell in the highest volumes over those that are energy efficient. Consistent with this assessment, another manufacturer stated that low cost models "are not well-featured products, so we're not going to put a lot of cost into the product to achieve ENERGY STAR."

Although our research did not directly address program strategies to resolve these challenges, program administrators may wish to investigate the potential of mid- and upstream approaches to increase the availability of efficient products at the low end of the market. While coordination across multiple program administrators would likely be necessary to influence retailers' and manufacturers' product design, assortment, and promotion decisions, these approaches may be able to overcome manufacturers' cost concerns and nudge retailers toward more efficient models.

Interview findings suggest a perceived lack of consumer demand likely further motivates manufacturers to prioritize price over efficiency in low end appliances. Manufacturers reported that energy efficiency is typically not a consideration for customers purchasing the lowest cost models, and stated these customers may not be willing or able to pay more for efficient products.

Efficiency programs promoting products that meet device-level energy use targets may be more effective in encouraging manufacturers to design efficient products at the low end than programs that promote specific efficient components. One manufacturer noted that established technologies can operate at a range of efficiency levels. According to this manufacturer, promoting device-level energy use targets, like ENERGY STAR standards, might encourage manufacturers to increase the efficiency of the established technologies more likely to be in the lowest-cost models rather than focusing on emerging technologies likely to appear only in high-end models. Thus, programs that encourage manufacturers to increase the efficiency of their products at a whole system level, rather than focusing on individual product components, may reach a broader swath of the market.

Manufacturers suggested that efficiency programs might benefit from leveraging existing promotional activities in the market. One manufacturer cited a promotion of heat pump water heaters in the Pacific Northwest as an example. According to this manufacturer, the efficiency program administrator timed its promotion of heat pump water heaters to coincide with manufacturer trade promotions that reduced the price to the retailer and with retail sales events that would further reduce the price to the consumer. The manufacturer noted that these combined promotions had resulted in notable increases in sales of heat pump water heaters. This type of promotion requires a great deal of coordination between efficiency program managers, retailers, and manufacturers. Market characterization research may be able to identify typical seasonal promotions for a program's targeted products that program managers could leverage, potentially allowing for greater lead-time in promotion planning.

3.5. Connected Appliances

All of the interviewed manufacturers are pursuing "smart" or "connected" appliances. These appliances may function as stand-alone devices, or they may be incorporated into a larger home network. The smart connectivity of appliances to the internet and cell phones, via Wi-Fi routers is designed to increase convenience for the consumer by:

- **Informing them when they may need to take action**, typically through a notification sent to a smart phone. For example, a connected dryer could alert a consumer that clothes are dry and ready to be removed. A connected cooking range could alert a consumer when water is boiling or the oven is preheated. A connected refrigerator could send an alert that the door was left open.
- **Providing remote control** of the appliance. For example, the consumer could start a load of clothes in the washing machine remotely so it would be ready to be transferred to the dryer when the consumer arrives at home.

- **Supporting identification and resolution** of problems. Connected features allow a smart phone to collect and transmit digital output from the appliance to repair call centers, allowing technicians to diagnose problems remotely.

Although manufacturers did not explicitly make the connection in interviews, these convenience benefits have the potential to enable energy-saving user behaviors. For example, alerts may allow users to add food sooner after a pot of water boils than they otherwise would, thus reducing cooking energy use. The ability to track data on appliance performance may support the identification and resolution of minor malfunctions that a user might otherwise ignore, although they could impact a device's energy performance. Further research could identify additional energy efficiency opportunities facilitated by connected devices, including the most promising device types for programs to focus on and opportunities for programs to promote energy saving connected features.

In addition to convenience benefits to the consumer, adoption of connected appliances has the potential to reduce demand on the grid, dependent on consumer behavior. For example, one manufacturer has developed a clothes dryer with smart features that could support its integration into demand response efforts. This model provides consumers with an alert before allowing them to start a load during a peak demand event. It also has the potential for direct load control: during a peak demand event, an aggregator or program administrator could remotely enable a setting on participating customers' dryers that would turn off or cycle the heating element, although the device would continue to tumble the clothes. The manufacturer reported enabling this feature could reduce each unit's energy demand from approximately 5,600W to approximately 200W, if it was operating at the time of the peak demand event. More research is needed to assess the technical potential of this opportunity. Additional research on appliance-user behavior is necessary to understand the potential impact of connected appliances on both energy use and demand since much of the savings are likely to be tied to consumer behaviors enabled by connected technologies, rather than the technologies themselves.

EPA staff have defined ENERGY STAR specifications to encourage the uptake of connected technology and offer clear and consistent criteria for connected appliances. ENERGY STAR staff reported working with stakeholders to revise test procedures to recognize connected appliances. ENERGY STAR criteria for connected appliances address both the appliances' consumer-facing interface and their demand response capabilities. For example, to earn an ENERGY STAR allowance, connected clothes washers must meet requirements related to the type of energy usage information they provide, how they transmit that information, and the ability to provide automatic curtailment.[1] EPA staff noted that ENERGY STAR connected appliance allowances may change as more data on the energy savings that connected appliances generate becomes available.

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1 The current ENERGY STAR clothes washer specification (Version 7.1) listing these requirements for connected devices is available at *http://www.energystar.gov/sites/default/files/ENERGY%20STAR%20Version%207.1%20Clothes%20Washers%20Program%20Requirements.pdf*.

Efficiency programs promoting connected devices may encourage additional manufacturers to enter the market. One manufacturer reported while they have invested research and development work into connected products with demand response capabilities, they are waiting for demand from consumers and utilities to increase before they introduce these features on the market. This manufacturer indicated that they would continue development of smart appliances with load control capabilities if utilities expressed interest in incorporating those appliances into their demand response programs, and if consumers demonstrate interest in those appliances.

3.6. Market Failures

The "Review of Effective Practices for the Planning, Design, Implementation, and Evaluation of Market Transformation Efforts" that the NMR Group prepared for the California IOUs in 2013 lists four broad types of market failure. According to the report, market transformation programs are justified in markets in which one or more market failures exist. This section reviews the market failure types listed in the NMR report and identifies the product categories to which they apply.

- **Price does not reflect external costs:** To the extent that external costs include energy costs, and the environmental costs associated with energy production, this market failure applies to all of the product categories discussed in this report. In each category, efficient products are more expensive than similar inefficient products despite their lower social cost. As a result, program intervention to address cost disparities between efficient and inefficient units may be justified for each product type.
- **Market actors have imperfect information about the product:** As noted above, manufacturers perceive a belief among some consumers that efficient clothes washers do not function as well as inefficient models. For clothes washers, and any other products facing similar barriers around consumer perception, program intervention to increase awareness of, and change attitudes toward, efficient products may be appropriate.
- **The product is a public good:** Public goods are goods or services for which there is very little incremental cost to provide to additional people, and to which it is very difficult to limit access to only those who have paid (Sebold, et al. 2001). None of the products included in this report are public goods.
- **The market suffers from imperfect competition:** The home appliance market is highly consolidated with large barriers to entry. In 2013, the top five appliance manufacturers accounted for nearly 80% of the U.S. market (Hagerty and Lee 2013). The implications of this consolidation on product energy use are unclear, however, and there is little an efficiency program could do to increase competition in the market.

4. Laundry

The Statewide PLA team originally selected clothes washers and not clothes dryers as the product to include in this research. Because new clothes dryer codes and specifications took effect in the study period, many of the opportunities manufacturers identified centered around clothes dryers rather than clothes washers. In addition, the Statewide PLA team expressed an interest in better understanding opportunities to pair efficient washers and dryers. Thus, the research team expanded the focus of this section to include both appliances, but clothes dryer research comes from manufacturer interviews rather than additional secondary research.

4.1. Product Overview

A residential clothes washer uses electricity to operate a pump and power a motor that agitates and spins clothes (DOE 2012a). The clothes are loaded into, washed, rinsed, and spun in a drum which sits inside a cabinet. Top-loading models often have an agitator, powered by the motor, which circulates the clothes in the drum. Top-loading models feature a drum on a vertical access whereas front-loading models have the drum on a horizontal access.

As defined by federal codes, the energy use of a clothes washer includes the energy used for heating water (consumed by the water heater), operating the machine, and drying the clothes (consumed by the dryer). The primary energy-using component of the washing machine itself is the electric motor, which accounts for about 10% of the total energy used by a typical load of laundry (DOE 2012a). The dryer energy attributed to the washer is determined based on the remaining moisture content (RMC) in the load leaving the washer. Washers with higher spin speeds that result in lower RMC in the clothes save energy because they reduce required drying energy (Firestone and Douglass 2015).

Dryers can have three types of heating elements: gas-fired, electric resistance, and electric heat pump (DOE 2014c). Heat pump dryers use a heat pump (condenser) to extract heat from the atmosphere to heat the clothes. They typically operate without venting, recapture the hot air used by the dryer and pump it back into the drum. Heat pump dryers have been available in Europe since the late 1990's (Ehrlich 2014). To keep drying times as short as current U.S. expectations, U.S. manufacturers market hybrid heat pump dryers, which combine a resistance and a heat pump element to reduce drying time in some settings.

4.2. Efficiency Specifications

New federal and ENERGY STAR standards went into effect in 2015 for both washers and dryers.

4.2.1. Clothes Washers

- **A revised Federal minimum standard for clothes washers took effect on March 7, 2015,** which will change the unit of efficiency from modified energy factor (MEF) to integrated modified energy factor (IMEF) and introduce separate standards for front- and top-loading washers (DOE 2015c). A higher IMEF indicates better energy efficiency. Additionally, the specification requires water usage to be expressed as an integrated water factor, for which a lower value indicates improved water efficiency.
  - Top-loading washers will face a two-phased standard change, increasing to 1.29 IMEF (1.72 MEF) in March 2015, and increasing to 1.57 IMEF (2.0 MEF) in January 2018. The 2018 standard for top-loading washers will amount to about a 33% energy savings and 19% water savings over 2012-2015 standards (ASAP 2015). Nationally, 2015-compliant models use an average of 770 kWh annually.
  - Front-loading washers will see standards increase to 1.84 IMEF (2.2 MEF) effective March 2015, which will result in approximately a 15% energy savings and 35% water savings over 2012-2015 standards (ASAP 2015). Nationally, 2015-compliant models use an average of 546 kWh annually.
- **Revised ENERGY STAR and CEE specifications also took effect March 7, 2015.** ENERGY STAR clothes washers use approximately 25% less energy and 40% less water than regular washers (ENERGY STAR 2015a).

Table 4-1 shows the IMEF, IWF, and unit energy consumption for ENERGY STAR and CEE compliant clothes washers.

Table 4-1: IMEF, IWF, UEC, and Unit Energy Savings (UES) Values for Clothes Washers (2015)

LEVEL	INTEGRATED MODIFIED ENERGY FACTOR (IMEF)	INTEGRATED WATER FACTOR (IWF)	ANNUAL UNIT ENERGY CONSUMPTION (UEC) (KWH/YEAR)*
Federal Standard (Top Load)	≥ 1.29	≤ 8.4	770
Federal Standard (Front Load)	≥ 1.84	≤ 4.7	546
ENERGY STAR (Top Load)	≥ 2.06	≤ 4.3	629**
ENERGY STAR (Front Load)	≥ 2.38	≤ 3.7	481
CEE Tier 1	≥ 2.38	≤ 3.7	Not available
CEE Tier 2	≥ 2.74	≤ 3.2	Not available
CEE Tier 3	≥ 2.92	≤ 3.2	Not available

* Includes dryer and water heating consumption.

** For an IMEF value of 2.04

Sources: CEE 2015, DOE 2012b Chapter 11.

- **The clothes washer itself uses a minority of the overall energy attributed to the clothes washer.** Table 4-2 shows that the majority of energy use attributed to the washer is actually consumed by the dryer.

Table 4-2: Disaggregated Washer Energy Use by Percent

	WASHING MACHINE	DRYER	WATER HEATER
Top-Loading	5%	59%	35%
Front-Loading	7%	71%	21%

Source: DOE 2012b

4.2.2. Clothes Dryers

Revised clothes dryer federal efficiency codes and new ENERGY STAR specifications went into effect in 2015. Modest federal energy conservation standards had been in place for 20 years, but new moisture sensors, automatic controls for heat sources, and ventless designs drove the adoption of updated regulations.

- As of January 1, 2015 all newly-manufactured residential clothes dryers sold in the U.S. must meet amended federal energy standards (DOE 2015b). Table 4-3 provides a summary of the requirements. For example, the former Energy Factor required for a standard-sized vented electric dryer was 3.01, and is now 3.73, or a 24% improvement in efficiency.
- ENERGY STAR-certified clothes dryers are at least 20% more efficient than the minimum federal standards seen in Table 4-3. This ENERGY STAR specification comes after two ENERGY STAR emerging technology awards in 2013 and 2014 recognized hybrid heat pump dryers (ENERGY STAR 2014c). Note that ENERGY STAR uses an optional federal test procedure that allows for automatic termination (DOE 2014b).

Table 4-3: 2015 Energy Conservation Standards for all Clothes Dryers

CLOTHES DRYER PRODUCT CLASS	FEDERAL MINIMUM CEF	ENERGY STAR MINIMUM CEF
1. Vented Electric, Standard (4.4 ft3 or greater capacity)	3.73	3.93*
2. Vented Electric, Compact (120V) (less than 4.4 ft^3 capacity)	3.61	3.8*
3. Vented Electric, Compact (240V) (less than 4.4 ft^3 capacity)	3.27	3.45
4. Vented Gas	3.30	3.48
5. Ventless Electric, Compact (240V) (less than 4.4 ft^3 capacity)	2.55	2.68
6. Ventless Electric Combination Washer/Dryer	2.08	No separate CEF

* Or vented

Note that the Federal minimum Combined Energy Factor (CEF) and ENERGY STAR minimum CEF values are calculated based on two different test procedures, and are not directly comparable.

4.3. Market Share

4.3.1. Sales

- **Front-loading washer new sales market share is decreasing.** Manufacturers and ENERGY STAR reported that front-loading washers have declined in market share, while high-efficiency top-loading washers are gaining market share. In 2009, front-loading clothes washers accounted for 45% of washers sold in the U.S. but in 2014, this proportion had declined to 30% (Wroclawski 2014). Manufacturers reported this could be due to price or consumer expectations about loading convenience and water use. ENERGY STAR reported this trend was likely due to consumer feedback.
- **ENERGY STAR washing machines have had a high market share for several years.** 2013 U.S. market penetration for ENERGY STAR clothes washers was 66%, and 64% in 2010 (ENERGY STAR 2013b, ENERGY STAR 2011).
- The total shipments of all residential clothes washers in the U.S. in 2013 was 7,503,200 (AHAM 2014), or 6.5% of national households. The average lifetime residential clothes washers is 14.2 years (DOE 2012b, Chapter 8).

4.3.2. Installed Base

- Seventy-nine percent of California homes have a clothes washer; of these, 27% are front-loading, 68% are top-loading, and 5% are stacked units (DNV GL 2014; Table 4-4). As of 2012, 58% of installed front-loading washing machines and 18% of top-loading machines met 2015 federal minimum efficiency standards.[2]

Table 4-4: Top-Loading and Front-Loading Clothes Washers

	CALIFORNIA STATEWIDE
Percent of households with clothes washer	79%
• Percent front loader	27%
– Percent front loader meeting 2015 federal minimum IMEF	58%
• Percent top loader	68%
– Percent top loader meeting 2015 federal minimum IMEF	18%
• Percent stacked	5%

Source: DNV GL 2014.

- Seventy-seven percent of California homes have a clothes dryer (DNV GL 2014). Clothes dryer fuel type varies considerably across the IOU territories: 60% of dryers in Pacific Gas & Electric Company (PG&E) territory are electric, compared with 31% in

2 Minimal differences across IOUs.

San Diego Gas and Electric (SDG&E) territory and 10% in Southern California Edison's (SCE) territory. The remaining are primarily natural gas, although a few customers use propane-fueled dryers.

4.4. Supply Chain

- **Major manufacturers continue to merge.** Electrolux-Frigidaire acquired General Electric's (GE's) appliance arm in 2014 (6% and 16%, respectively, clothes washer market share in 2008), but Whirlpool-Maytag will continue to hold the largest market share (64% in 2008; DOE 2012b Chapter 3; Barry 2014).
- Sears, Lowes, Home Depot, and Best Buy account for 68% of 2013 major appliance sales market share nation-wide (Kapner 2013).[3]

Otherwise, the 2012 Home Energy Efficiency Rebate (HEER) report summarizes the most up-to-date supply chain information available (Research Into Action 2012, Study # SCE0306).

4.5. Cost

- **In-store availability of lower price-point ENERGY STAR clothes washers is limited.** For top-loading washers, ENERGY STAR-certified models are available at price points over $500, while all non-ENERGY STAR models were under $600. All front-loading models available in-store are ENERGY STAR-certified. Figure 4-1 and Figure 4-2 represent in-store availability of ENERGY STAR and non-ENERGY STAR models in two California stores.[4]

3 This source includes all major appliances; product-specific market share data are not publicly available.

4 The selection of the stores began by identifying major appliance retailers and visiting their websites. Only two of the top five retailer websites presented information for in-store availability and ENERGY STAR designation in an accessible format; these were Sears and Lowes. The availability of the stores have been added together, which approximates retailer choice, but may include duplicate models.

Figure 4-1: 2015 Availability of Top-Loading Washers in Two California Stores

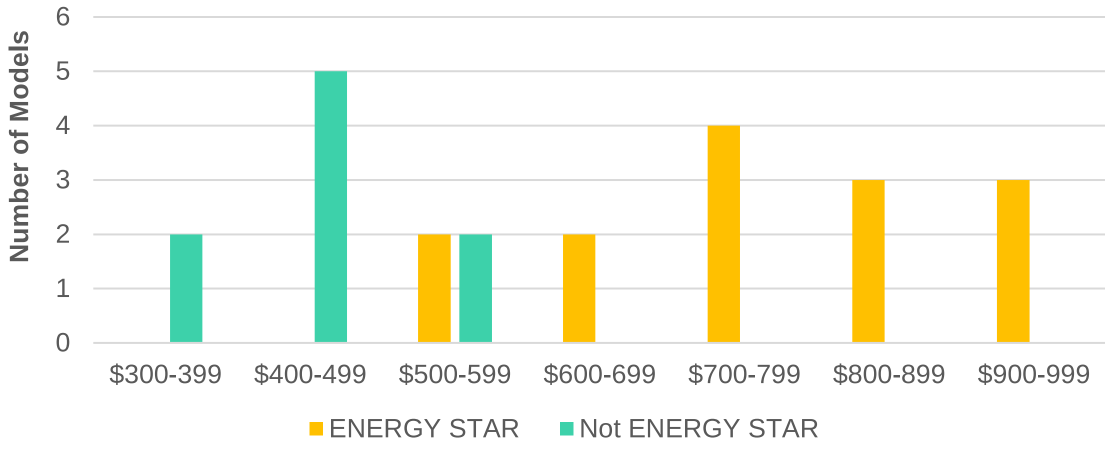
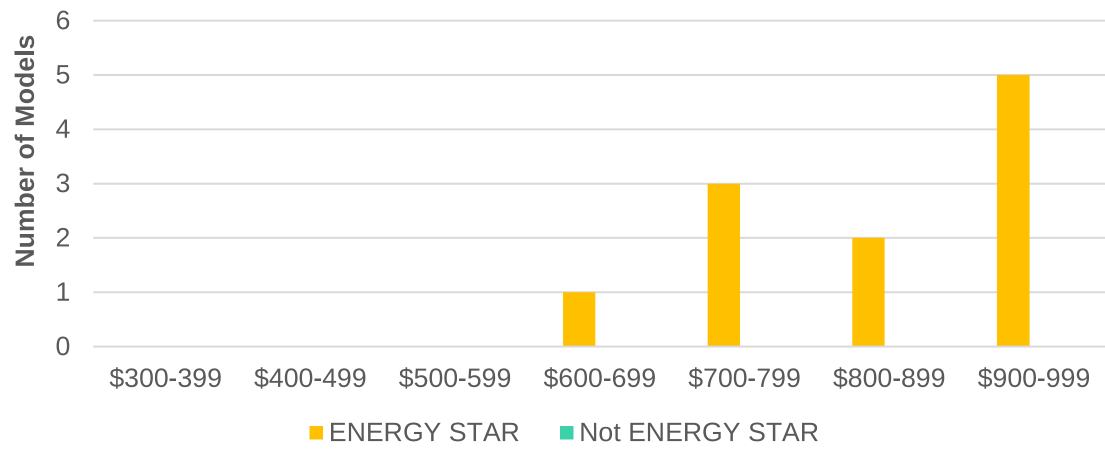


Figure 4-2: 2015 Availability of Front-Loading Washers in Two California Stores



- In 2010, the estimated **incremental** cost to manufacture an ENERGY STAR unit over a 2015 base case unit was approximately $61 for top-loading machines and $56 for front-loading machines (DOE 2012b Chapter 5).
- Consistent with our online retail research, manufacturers report that front-loading clothes washers cost $100-$200 dollars more than equivalent top-loading machines.

4.6. Consumer Attitudes and Behavior

- The average American family washes 300 loads annually (ENERGY STAR 2015a). Some sources estimate up to 365 loads per year (Amberg 2014).
- A national survey found that customers reported similar levels of satisfaction with front-loading versus top-loading washers (808 versus 789 out of 1000; J.D. Power 2014).

- **Most washer-dryers are purchased in pairs.** A national survey estimates that 79% of clothes washers and dryers are purchased as a set (J.D. Power 2014). Manufacturers confirmed that 80-90% of high-end models are sold in pairs.

4.7. Barriers and Benefits

Although there are substantial energy and non-energy benefits to efficient clothes washers, we identified several consumer barriers to purchasing efficient washers and manufacturer barriers to producing efficient washers.

4.7.1. Consumer Barriers to Efficient Washer Uptake

There are a number of barriers to efficient washer uptake, mostly around consumer perceptions of the features and water use required to effectively clean clothes, and cycle time. Although many efficient top-loading washers no longer require agitators to clean clothes, some manufacturers have installed center axes due to customer perceptions. Further, many efficient washers come with higher-water use cycles. Manufacturers also described several consumer attitude barriers surrounding the uptake of efficient front-loading washers.

Several factors may make front-loading washers less attractive to consumers than top-loading washers. Manufacturers and other sources suggest that consumers perceive several barriers to front-loading washers.

- **Front-load washers have somewhat longer cycle times than top-loading washers.** On average, high-efficiency top-loaders took 60-90 minutes to do an eight pound load on normal wash while the front-load washers took 75-100 minutes to do the same (Consumer Reports 2014).
- **Front-loaders are more difficult to access.** To address this, some manufacturers sell washer pedestals costing about $250. One manufacturer has built in "risers" that increase the washer's height (Consumer Reports 2014).
- **Front-loaders have higher initial cost.** Front-loaders are $100-$200 higher in price than high-efficiency top-loaders (manufacturer interviews).
- Mold may form around the front-loading gasket (Hood 2014).
- Front-load washers may not allow for mid-cycle access (DOE 2012a).
- Perceived insufficient water (manufacturer interviews).

4.7.2. Manufacturer Business Challenges to Increasing Clothes Washer Efficiency

- **Manufacturers design washers and dryers with paired features, which affects how they incorporate potential efficiency upgrades in products.** Manufacturers design washers and dryers in pairs, matching price range, aesthetics, capacity, and cycle time.

This affects how manufacturers incorporate potential efficiency upgrades in their products: shortening the spin cycle time or using heat pump technology that lengthens the drying time results in damp clothes sitting in the washing machine while the previous load is drying.

- **Manufacturers expressed confusion about accounting for energy savings across washer and dryers.** With the introduction of ENERGY STAR specifications for clothes dryers, manufacturers are concerned that clothes washers will not continue get energy savings "credit" for increasing spin speeds and reducing RMC, one of the main remaining opportunities to increase washer efficiency and make heat pump dryers more attractive to customers. In fact, because the energy use specifications allocate dryer energy use to the washer, reducing moisture content is reflected in overall clothes washer-allocated energy savings according to current federal efficiency codes.
- **Cleaning performance has emerged as a limiting factor to improving efficiency.** Manufacturers voiced concerns about maintaining the cleaning efficacy while continuing to increase the efficiency of washers.
  - One manufacturer reported that they are reaching the limit of "being able to deliver further efficiency gains while maintaining the wash performance demanded by consumers." This finding is consistent with findings from industry literature that "the historical improvements in efficiency are so large that little headroom remains for incremental [energy savings] potential" (BPA 2015, 8).
  - ENERGY STAR has recognized this limitation and will invest resources to better understand the relationship between energy, water, and cleaning performance. ENERGY STAR expressed that they do not want energy efficiency gains to compromise cleaning performance because that would hurt consumers' perceptions of the ENERGY STAR brand and the brands of their partners.
  - ENERGY STAR is collaborating with the DOE and the EPA to create opportunities for discussions with stakeholders on how to develop a test procedure for cleaning and rinse performance (ENERGY STAR 2015a).
- **Manufacturer feedback suggests that they perceive consumer attitudes about efficient features as a barrier to uptake of efficient technologies.** Manufacturers reported consumer adoption barriers to front-load washers, reporting that they are less user-friendly than top-loading washers and citing many of the barriers above. They reported these attitudes would need to be addressed to increase market share of front-loading washers.
  - Manufacturers report that enduring customer attitudes do not reflect existing product offerings. For example, some front-load models on the market already allow mid-cycle access and consumers already bend down when using dryers as almost all clothes dryers are front-access.

- One manufacturer is launching a new washer that incorporates a sink-like pre-wash feature in response to consumer behavior research that showed many people were pre-wetting their clothes in the sink before washing them, which was wasteful and messy.

4.7.3. Benefits of Efficient Washers

There are several non-energy benefits (both environmental and consumer experience-related) resulting from the use of efficient clothes washers: (Li et al. 2004, Consumer Reports 2014)

Environmental	Consumer experience	Benefit
✔		Less water use
✔	✔	Less laundry detergent use
✔	✔	Higher spin speeds can mean shorter drying times
	✔	Reduced wear and tear on clothing from shortened or removed agitator
	✔	Cleaner clothes
	✔	Less noise

While it is difficult to quantify these non-energy benefits for use in cost-benefit analyses, these benefits may appeal to end-users and could thus be valuable considerations in consumer awareness efforts.

4.8. Clothes Dryer Market and Technology Trends

- Forty-five models of ENERGY STAR certified clothes dryers were available nationwide as of February 15, 2015 (EPA 2015). ENERGY STAR models include both electric and gas, made by several manufacturers.
- Manufacturers primarily meet ENERGY STAR specification requirements in conventional dryers by incorporating advanced sensors that more effectively detect when clothes are dry and stop the dryer.
- **Hybrid heat pump clothes dryers are now available in the U.S. market and offer a substantial savings opportunity for electric clothes dryers.** Heat pump clothes dryers are up to 40% more efficient than standard dryers (EPA 2015). Manufacturers described heat pump clothes dryers as a major technology change that represents new, untapped energy savings potential. Heat pump dryers have been available in international markets since the 1990s.
- **Manufacturers predict slow market adoption of this technology.** Manufacturers expect this type of dryer to have a limited, "early adopter" market share at first. As heat pump dryers need additional time to dry clothes, manufacturers reported that consumer

education will be needed in order for heat pump dryers to gain wider acceptance. Incentives are important as well. Some manufacturers reported they are holding back on mass production of heat pump dryers in this first year. A major retailer predicts that the same people and regions that have adopted heat pump technology in ductless heat pumps and residential water heaters will find heat pump clothes dryers appealing.

- **Hybrid heat pump dryers are at the high end of pricing.** At around $1,500, manufacturers report that current hybrid heat pump dryers appeal to a limited market segment, unless rebates are high enough to bring price parity with conventional technology.
- **Manufacturers predict that longer drying times of heat pump technology will be a barrier to consumers.**

4.9. Technical Opportunities to Increase Clothes Washer Efficiency

- Manufacturers echoed that there is still room to improve washing efficiency, especially in water usage.
- **ENERGY STAR and manufacturers reported somewhat different opinions about the opportunity to further increase clothes washer efficiency.** ENERGY STAR underscored that they see continued opportunity for improving clothes washer efficiency. Manufacturers reported that current clothes washers are a relatively mature technology with few opportunities to increase unit efficiency, but that there are a few remaining opportunities to reduce energy use. The manufacturers said that improving the efficiency of a washer is not a matter of replacing a single component; instead it involves a combination of elements including cycle time, water amount and temperatures, sensors, motors, detergents, ball bearings, and drum type. They also reported that many energy-saving technologies are becoming more common at lower price points. Manufacturers additionally commented that further efficiency gains would have to ensure that cleaning performance is not compromised.
  - **Increased drum capacity** allows the user to clean the same amount of laundry with fewer loads (ENERGY STAR interview).
  - **Increased spin speeds** can decrease laundry energy use, by slightly increasing clothes washer energy use in order to decrease dryer energy use. Manufacturers reported increasing spin speeds would require other changes, including different ball bearings and a stainless steel rather than a porcelain drum.
  - Adding a **cleanliness sensor** allows the wash cycle to shut down sooner if it senses the clothes are clean, shortening wash cycle times and reducing energy use.
  - Some manufacturers are emphasizing **water conservation**, reporting that there is more opportunity there. Through reducing hot water use, these changes will also increase washer efficiency.

4.10. Washer-Dryer Pairing

Designing efficient washer-dryer pairs may facilitate increased uptake of both most-efficient front-loading washers and hybrid heat pump dryers. Manufacturers anticipate creating and emphasizing energy efficient laundry pairs by matching new heat pump dryer and other ENERGY STAR dryer models with similar ENERGY STAR washers. Paired incentives mimics the manufacturer design process, and manufacturers reported that this could help accelerate the adoption of both. For example, manufacturers report that pairing a high spin-speed washer (not on the market) with a heat pump dryer would decrease drying time, reducing one of the barriers to heat pump dryer uptake. One manufacturer expected 90-95% of heat pump dryers to sell as pairs with high-end washers. However, these paired incentives could increase costs for customers because this pairing would emphasize dryer efficiency mostly for feature-rich washer-dryers at high price points.

4.11. Conclusions

Manufacturer interviews are consistent with industry literature in suggesting that additional efficiency improvements in clothes washers are likely to result from incremental improvements to the efficiency of existing technologies. Manufacturers did not describe new technologies entering the market likely to dramatically alter washer energy use and expressed concern that further efficiency gains might compromise cleaning performance. Nonetheless, there may be an opportunity for consumer education to counter perceived convenience and performance deficiencies of front-load washers relative to less efficient top-loading models.

Heat pump dryers provide a significant opportunity for energy savings relative to dryers using exclusively electric resistance heat, although the models available are at the high end of the market. Education to owners of heat pump dryers may be necessary to ensure that users minimize use of the units' resistance heating elements, which manufacturers install to reduce drying time. Pairing of efficient washers with heat pump dryers may help to address some of the characteristics of heat pump dryers that could limit consumer adoption, as reducing the remaining moisture content in clothing would reduce drying times.

5. Residential Cooking Products

5.1. Product Overview

Residential cooking products describe a group of kitchen appliances that includes stoves, stovetops, cooktops, kitchen ranges, ovens, microwave ovens, microwave convection ovens, and wall ovens. Residential cooking products can be custom-installed or "drop-in" models in standard widths for the kitchen cabinetry. DOE defines a "conventional range" as a cooking product that "consists of a *conventional cooking top and one or more conventional ovens*." DOE does not regard ranges as a distinct product class because it has determined that any potential cooktop or oven standards would apply to components of a range separately (DOE 2009).

Indeed, on June 10, 2015, DOE issued a Notice of Proposed Rulemaking to improve the energy use of ovens, whether installed as a wall oven or as part of a range. DOE typically divides these products into electric or gas product classes, with or without a self-cleaning feature.

Cooking products cook or heat food by means of gas, electric resistance, electromagnetic induction, or microwave energy. Cooking products do *not* include portable or countertop items that use electric resistance heat for baking or are designed to use a standard electrical supply of approximately 120 volts (i.e. toaster ovens, hot plates, electric frying pans, or slow cookers). Cooking products also do not include appliances designed to cook food outdoors.

5.2. Efficiency Specifications

Existing energy specifications for cooking products cover power use when the appliance is "off." Constant burning pilot lights have been prohibited in gas ovens, ranges, or cooktops with an electric supply cord manufactured since 1990. In April 2012, gas cooking appliances without electric cords were also required to forgo constant burning pilots.

- Baseline electric ranges use approximately 290 kWh per year (Baldwin and Chan 2011). Baseline self-cleaning gas ranges which had electronic oven ignitions used 3.87 MMBtu per year along with 56 kWh.

New microwave specifications will reduce standby power to 1 Watt in 2016 (DOE 2013). On June 17, 2013, DOE published first-ever standards for microwave ovens, regulating their power use while in standby mode (78 FR 36316). The rule will affect microwaves manufactured or imported in the United States after June 17, 2016. Under the regulations, new microwaves will reduce their standby power use by half or three-quarters, depending on the product class. Microwaves currently use up to four watts of standby power to run the clock and user display.

- Microwaves are typically used to heat food about 70 hours per year, so their power use the other 8690 hours is a key to energy conservation. In the maximum scenario of a 75% power reduction, a microwave will use 8.69 kilowatt-hours per year, instead of 34.76 kWh per year. When multiplied over the large majority of households with a microwave, and because this reduction is independent of user behavior, this estimate of 26 kWh per year results in substantial overall impact.

There is currently no ENERGY STAR specification for microwaves, cooktops, or ovens.

The DOE is in the process of revising cooking product test methods. DOE sees energy savings opportunities in cooking devices and initiated a process to develop efficiency standards in 2006. The Energy Policy Act of 2005 required DOE to conduct two cycles of rulemakings to determine whether to amend cooking product standards, by finding them technologically feasible and economically justified. DOE published a "framework document" March 15, 2006 describing approaches DOE anticipated and the issues to be resolved in rulemaking. Technical support documents such as life-cycle cost analyses and payback periods for various appliance components were made available. At the time it was thought that energy-manufacturing standards might be finalized by 2012.

The rulemaking process proposed in 2006 has been delayed for nine years by consistent objections to proposed test procedures for cooktops. A review of DOE rulemaking dockets indicates that commenters think stovetop energy use is most-appropriately tested by water heating protocols, rather than the current heating protocol that heats an aluminum block with a steel base, particularly for induction burners. In December 2014 DOE asked for public comments on a third round of revised test methods (DOE 2014c).

The DOE proposed new minimum efficiency standards for conventional ovens in June 2015. DOE has determined that new and amended energy conservation standards for residential conventional cooking products will save significant energy and "are technologically feasible and economically justified"; the three criteria they are mandated to meet. On June 10, 2015 DOE issued a Notice of Proposed Rulemaking that would amend oven manufacturing to reduce standby/off power, improve insulation, and reduce vent rates (DOE 2015a). This proposition would affect ovens sold in the U.S. after January 1, 2019 if there is no further delay.

On February 11, 2015 AHAM and Underwriters' Laboratories Environment released a voluntary sustainability standard for household cooking appliances. A manufacturer recommended these voluntary standards as the template DOE should follow in their rulemaking. The cooking products covered in the standard include gas or electric convection, non-convection, and steam products such as ranges, built-in cook tops, and ovens. This new standard is the fourth in a family of product sustainability standards under development by AHAM, CSA Group, and UL Environment intended for use by manufacturers, governments, retailers, and others to identify environmentally preferable products. The standard takes a lifecycle approach for identifying the environmental impacts of household cooking appliances in five key areas: materials, manufacturing and operations, energy consumption during use, end-of-life, and innovation. These voluntary standards are available free of charge to members of AHAM and to others for a fee.

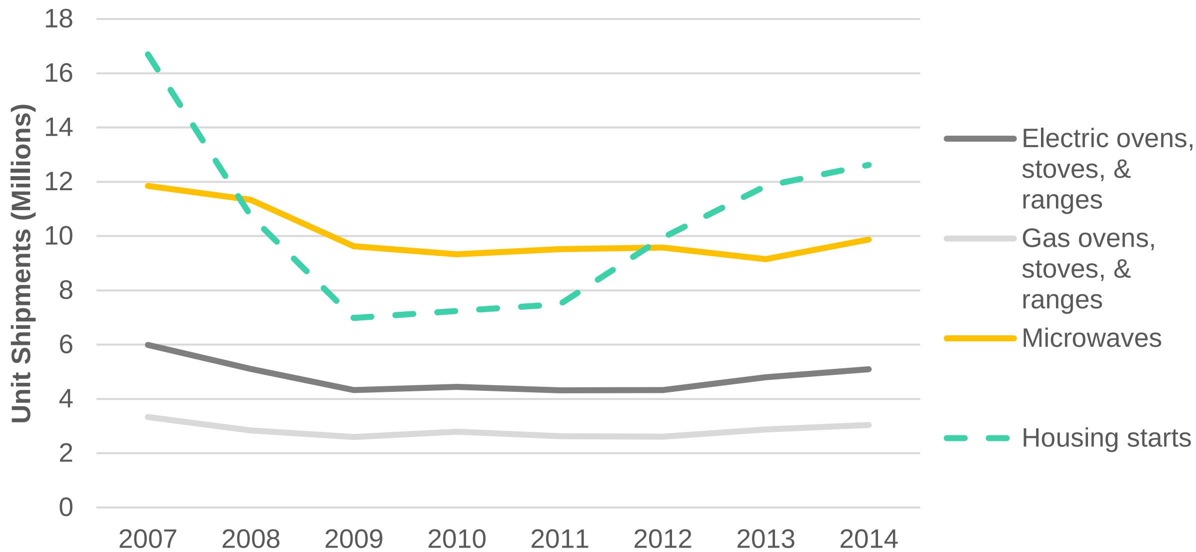
5.3. Market Share

One major retailer reported that induction burners were currently 20% of that retailer's cooktop sales and are "steadily increasing." Two other manufacturers reported they expect induction sales to increase. ENERGY STAR staff mentioned induction cooktops is the energy-saving technology they encounter most often in conversations with partners and at appliance trade shows.

5.3.1. Sales

Although fluctuations in the cooking products industry are not as extreme, sales of cooking products largely reflect changes in the housing market. Sales of all product categories declined as the housing market declined from 2007 to 2009, were largely flat until 2011, and began to increase as the housing market recovered in 2012 and 2013 (Figure 5-1).

Figure 5-1: U.S. Unit Shipments of Cooking Products, 2007-2014



Data on electric and gas ovens, stoves and ranges from Statista.com citing *AHAM 62nd Annual Appliance Industry Forecast (March 2014).* 2013 shipment totals are projections, and those after 2013 are forecasts.

Data on microwaves from *Statista.com citing AHAM Appliance Magazine (ID220122).* Shipments for 2015 and 2016 are forecasts.

Data on housing starts from U.S. Census Bureau. *Annual Rate for Housing Units Authorized in Permit-Issuing Places: United States*, Seasonally Adjusted Total Units, 2005 to 2015. Accessed May 21, 2015.

Of the cooking products studied, microwaves were sold in the highest volumes. Industry estimates suggest that, between 2007 and 2014, microwave shipments were, on average 32% greater than shipments of all other types of stoves, ovens, and ranges combined[5] (Appliance Design 2015).

Ranges make up the large majority of non-microwave cooking product shipments. Ranges made up 86% of the gas cooking products and 79% of the electric cooking products (excluding microwaves) shipped in the U.S. between 2007 and 2014. Separated stovetops or wall ovens are less common, typically custom installations.

Analysts expect the cooking appliance market to remain largely flat in the near future. Analysts anticipate that large cooking appliances will see year over year volume growth of 1% between 2014 and 2019 (Euromonitor 2015a). Consistent with these projections, analysts anticipate that the total value of shipments of household cooking appliances manufactured in the United States will remain relatively constant through 2020, at approximately $3,600,000 annually.

5 As referenced by Statista (2015 March) "Total unit shipments of microwave ovens in the U.S. from 2005 to 2016." Association of Household Appliance Manufacturers: applianceDESIGN, Issue March 2015, page 5.

Gas appliances are more prevalent in California's installed base than national shipment data would suggest. The 2012 CLASS found that, statewide more than two-thirds of California homes use natural gas in their cook tops and more than half use natural gas in their ovens (DNV GL 2014; Table 5-1). In contrast, 61% of the ranges shipped nationally between 2007 and 2014 were electric. Electric appliances also made up a slight majority (50.3%) of stand-alone cook top shipments and nearly all (94%) stand-alone oven shipments.

Table 5-1: Cooking Appliance Fuel Types in California by Utility from CLASS 2012 (n=1987)

UTILITY TERRITORY	NATURAL GAS	ELECTRIC	PROPANE	TOTAL
		Cook Tops		
PG&E	57.5%	37.4%	5.1%	100%
SCE	79.2%	18.4%	2.5%	100%
SDG&E	58.7%	38.9%	2.4%	100%
All California	66.9%	29.5%	3.7%	100%
		Ovens		
PG&E	46.3%	49.2%	4.4%	100%
SCE	69.8%	28.2%	2.0%	100%
SDG&E	49.1%	49.4%	1.5%	100%
All California	56.7%	40.3%	3.0%	100%

Unlike the unit shipment data listed above, the CLASS dataset uses the term "ranges" to describe all cook tops, whether or not they are integrated into a single appliance that also includes an oven. Likewise, data on ovens includes both stand-alone units and those sold with integrated cook tops, which unit shipment data describe as a "range."

5.4. Supply Chain

While little publicly-available market research data are available, the cooking products market appears to be concentrated among a small group of manufacturers. Publicly available market research reports focus on the "large cooking appliance" market in aggregate, which includes products like ventilation hoods in addition to ovens, stoves, and ranges. In 2013 GE led the large cooking appliance market in the U.S., accounting for 24% of shipment volume (Euromonitor 2015a). Whirlpool had the next highest market share, with 21% of U.S. shipments. Broan-NuTone LLC, a manufacturer of ventilation hoods that does not appear to make ovens and stoves, was the third largest manufacturer in the category, with a 20% share.

No publicly available distribution channel information was located specifically for residential cooking products. The DOE's distribution channel analysis cites 2005 data suggesting that 93% of residential appliances are distributed directly from manufacturers to retailers (DOE 2009).

5.5. Cost

Consumer choice includes a wide range of prices, from around $400 to over $5000. Cooking appliances used in homes are also offered in a wide list of models and configurations. Despite hundreds of combinations, the all-in-one kitchen range (with at least four burners and at least one oven) makes up 86% of the gas cooking products and 79% of the electric cooking products (excluding microwaves) shipped in the U.S. between 2007 and 2014 (Euromonitor 2015a). One major national chain lists 193 models of ranges, 42 models of cooktops, and 56 models of wall ovens. An independent Oregon retailer lists over 800 models of kitchen ranges in 25 brand names they carry or can order, and Sears lists over 500.

To present typical consumer costs, the following table describes the lowest and highest price points for seven common types of *freestanding*, white, cooking ranges at a *standard* width of 30 inches.

Table 5-2: Snapshot of Prices for Typical Kitchen Ranges

KITCHEN RANGE TYPE	LOWEST PRICE FOUND	HIGHEST PRICE FOUND	COMMENTS
Basic Electric Range	$329 (Sears)	$719 (Lowes)	White, coil burner elements, a storage drawer. Amana, Frigidaire, GE, Hotpoint, Premier, Kenmore.
Self-Cleaning Electric Range	$405 (All)	$809 (Lowes)	Better insulation, high-temperature capability for clean cycle. Most have smooth cooktops, some have warming zones, bigger windows. More brands and sub-brands.
Smooth Electric Cooktop Range	$449 (Lowes)	$1499 (Sears)	Five burners become common. Convection fan in ovens and warming drawers begin at $719 up to $1439. Dual oven choices are $1079 to $2699. Fisher & Paykel brand appears at $3500.
Induction (Smooth) Electric Cooktop	$1499 (Sears)	$2519 (Lowes & Sears)	All induction cooktop models have convection technology in the oven. Double oven KitchenAid at $2519. Fisher & Paykel appears at $4800.
Standard Gas Range	$359 (Lowes)	$1457 (Lowes)	Standard burners are now less common than sealed. Five burners become available at $719.
Self-Cleaning Gas Range	$519 (Sears)	$1304 (Independent)	5-burners begin $848. Double ovens begin at $1399 at Sears, not listed in own row.
“Commercial-Style” Gas Range	$2899 (Independent)	$5769 (Lowes)	Thermador, Wolf, Dacor, GE Profile, GE Café, Electrolux Icon, KitchenAid. Six burners and 36” widths are common.

* Other colors than white cost more, especially stainless steel; $80 to $300 more.

** Drop-in and slide-in models ready for custom installation cost more; $200 to $500 more.

5.6. Attitudes and Behavior

Non-energy benefits are driving growing sales of induction stoves. Multiple manufacturers stated they had either experienced or expected an increase in shipments of induction stoves. One manufacturer described “a lot of reasons why someone would buy induction” in addition to energy efficiency. According to manufacturers, induction stoves heat food faster, are easier to clean, and are less likely to burn those using them than other technology types.

5.7. Barriers and Benefits

While the lack of an accurate test procedure or national efficiency specification (discussed below) are pose challenges to manufacturers, there are also several consumer barriers to the uptake and classification of efficient cooking products.

Consumer interest in energy efficiency of cooking products may be low. Manufacturers reported that energy efficiency is not a primary concern for most consumers in purchases of cooking products. While the prevalence of ENERGY STAR labels have helped develop consumer awareness of energy efficiency in other appliance purchases, energy use would be a new consideration for most consumers in purchases of cooking equipment.

Consumer behavior may have a larger impact on energy use than the efficiency of their cooking equipment. Manufacturers consistently described cookware choice, methods, temperatures, and timing as the biggest determinants of cooking energy use. As one manufacturer described:

> "We each have the same box of mac and cheese, but we cook it differently. I might use more water than you to boil the same amount of pasta. I might put the pasta in before the water starts to boil and you wait. I might put the lid on, and you don't. That all contributes to the variability in energy use, and is hard to account for in the test procedure, one can only approximate."

As a result of this variation, manufacturers noted that it may be difficult to verify energy savings from improvements in cooking equipment efficiency as variation in cooking behaviors may overwhelm predicted savings based on controlled testing results. According to one manufacturer, "you have to realize that savings in the lab might never happen in the real world." Manufacturers recommended that any efficiency programs focused on cooking equipment include consumer education elements.

"Commercial-style" or "pro-" ranges, which burn gas faster than traditional residential models, are an area of growth in cooking products. In some cases, these models have as many as six burners, bridges between burners to make a grill, and high-input burners. Analysts report that growth in sales of these models reflects a rising interest in gourmet cooking among consumers in the U.S. and U.K. Leading brands include Wolf, GE and Viking (Euromonitor 2015a). Wolf ranges are manufactured in the U.S. by the SubZero Group, a visible participant U.S. DOE cooking performance test procedures.

5.8. Technical Opportunities to Increase Efficiency

Ovens and cooktop design decisions can improve cooking efficiency within reasonable payback periods (LBNL 2004). Smaller ovens offered beside larger ones in one-piece ranges, along with forced convection features, are currently marketed as time *and* energy savers, on sales websites such as Whirlpool, Lowe's and Home Depot.

In addition to providing baseline average prices, DOE technical support documents calculated the additional cost of energy efficiency components, and energy-cost payback periods with data collected in 1996 and 2006, projected for 2012 (Baldwin and Chan 2011). The following table, a small portion of the technical support documents available, show which energy efficiency improvements are within the cooking product lifetime of 19 years used by DOE for both types of ovens and cooktops.

Table 5-3: Baseline, Savings, and Cost of Energy Efficiency Opportunities for Ovens

OPPORTUNITY	ENERGY USE/SAVINGS	DESCRIPTION	PRICE INCREASE
Electric Oven	**154 kWh UEC**	**Standard oven**	**$524**
Reduced Vent Rate	4%	Decreasing the size and/or adding baffles to reduce the oven's outgoing airflow, required for moisture release.	+$ 3.76
Improved Insulation	4%	Increasing thickness and/or density of oven wall insulation.	+$ 7.40
Improved Door Seals	2%	Reducing conduction heat loss from the oven by increasing "thermal break" properties of the door seal.	+$ 8.51
Electric Self-Cleaning Oven	**159 kWh UEC**	**Increased insulation and self-cleaning feature**	**$755**
Bi-Radiant Oven	30%	(Note: payback period is 30 years)	+$ 143
Gas Standard Oven	**1.71 MMBtu UEC**	**Electric Glow-Bar or Electronic Spark Ignition**	**$647-$654**
Improved Insulation	5%	Increasing thickness and/or density of oven wall insulation.	+$ 8.26
Improved Door Seals	2%	Reducing conduction heat loss from the oven by increasing "thermal break" properties of the door seal.	+$ 2.49
Forced Convection	4%	Reducing cooking time, cooking temperature, and therefore fuel use with a 20-30 Watt fan distributing oven air evenly.	+$51.09
Reduced Vent Rate	0%	Decreasing the size and/or adding baffles to reduce the oven's outgoing airflow, required for moisture release.	+$ 3.74
			Continued
Gas Self-cleaning Oven	**1.11 MMBtu UEC**		**$954**
Forced Convection	16%	Reducing cooking time, cooking temperature, and therefore fuel use with a 20-30 Watt fan distributing oven air evenly.	+$25.38
Red. Conduction Losses	0%	Upgrading the oven door by modifying an inner panel, and/or the window.	+$10.07
Improved Door Seals	0.8%	Reducing conduction heat loss by upgrading the "thermal break" properties of the door seal.	+$ 2.81

* Self-cleaning ovens use additional non-cooking energy during high-temperature cycles.

Source: Baldwin and Chan 2011

Table 5-4: Baseline, Savings, and Cost of Energy Efficiency Opportunities for Cooktops

OPPORTUNITY	ENERGY USE/SAVINGS	DESCRIPTION	PRICE INCREASE
Electric Cooktops	**132.5 kWh UEC**	**Smooth or Open Coil**	**$304-$405**
Improved Contact Conductance (Open coil only)	4%	Increasing flatness of burners to improve contact with pan for maximum heat conductance. Consumer controls quality of pan flatness on the other side.	+$ 4.79
Reflective Surfaces (Open coil only)	5%	Highly polished or chromed surfaces of drip pans that reflect radiant heat back toward the pan. Require consumer cleaning to work "as tested."	+$ 6.36
Induction Elements (Smooth only)	12%	Sealed burners work by electromagnetic induction on ferrous pans.	+$591.00 (Payback 422 years)
Gas Cooktops	**0.75 MMBtu UEC**	**Electronic ignition**	**$385**
Sealed Burners	5%	Cooktop surface surrounding sealed burners butts directly up against the burner, leaving no open area as in standard gas burners. Estimated 2% efficiency increase due to reduced pan-to-burner separation and better main aeration, from manufacturer data.	+$42.05
Reflective Surfaces	0%	Highly polished or chromed drip pans. Manufacturer data suggests 0.01% efficiency improvement.	+$12.91
Thermostatic Burners	0%	Contact sensor adjusts gas flow according to pan bottom temperature. DOE test method precludes detection of savings, but design might save energy.	+$35.59

Table 5-3 and Table 5-4 do not include additional design components whose energy savings payback may exceed appliance life, or are disputed. In electric ovens, bi-radiant design (reflective walls focusing the heat), oven separators (right-sized oven cavities inserted by users), door upgrades for self-cleaning models, and forced convection features all had payback periods exceeding 30 years. Gas oven separators' payback exceeded 50 years. In cooktops, the features not presented are smooth radiant elements, which actually increase energy use, and smooth halogen lamp elements, whose estimated payback exceeded 1000 years. Although smooth top induction elements also have a payback period that exceeds appliance lifecycle, they are included in the table for comparison, because of their prevalence. Many excluded components likely have non-energy benefits and consumer utility.

Manufacturers and EPA reported induction cooktops are likely more energy efficient, however induction may never be cost-effective based on energy savings. Induction improves cooking efficiency by 10%, or from 74% to 84% efficiency, in DOE testing of smooth element cooktops. This saves at least 15 kWh per year (Baldwin and Chan 2011). However, induction's price premium of $591 causes the payback period to be more than 400 years. Even if prices for induction cooktops were reduced by 75%, the payback on 15 kWh per year would still exceed 100 years. The EPA and some manufacturers both described non-energy benefits of induction that are motivating consumer adoption, including speed, safety, and ease of cleaning.

Microwaves offer a behavioral opportunity to save energy in cooking, particularly in hot climates. As California's Consumer Energy Center (CEC) reports: "Fast and efficient microwaves use from 30 percent to as much as 80 percent less energy than conventional ovens. They have the added benefit of not heating up the kitchen, so they can save energy on air conditioning…" (California Energy Commission 2015). For example, they report that cooking a casserole used about 0.36 kWh in the microwave, 1.39 kWh in a convection oven, and 2.0 kWh in an electric oven. However, these savings would be difficult to quantify and there would be consumer barriers to overcome because microwaves cannot brown food and sometimes cook food unevenly.

5.8.1. Policy Setting Needed

Minimum energy standards have just been proposed in oven manufacture, but agreement on cooktop test procedures is needed. California utilities are already engaged in commenting on public dockets regarding the DOE test procedure. Precise energy input, heated material temperatures, and cook times are standardized and measured to produce cooking efficiency and operating cost estimates. To summarize the debate, many manufacturing representatives and efficiency advocates think the test should be based on heating water in a pan, in order to accommodate new induction technology and to better emulate home cooking. Instead, the procedures as proposed continue to heat an aluminum test block with a steel base. DOE's tests obtained irregular results when using water heating protocols.

A secondary issue has arisen in how to test "high-input" gas burners on commercial-style cooking products, or whether to make these high-end ranges another product class left out of the 'conventional cooking product' rulemaking.

A review of DOE rulemaking docket's comments and memos suggests that the current test of a stove burner may be unsuitable for new induction technology. Manufacturers expect that induction cooktops will eventually be shown to use less energy when adequately-designed testing is developed. Manufacturers did not otherwise mention upcoming energy efficiency improvements in ranges or stoves, viewing the resolution of testing method conflict as the first step in the energy efficient product design cycle.

5.9. Conclusions

The two largest energy savings opportunities in large cooking appliances – shifting from electric resistance cooktops to induction cooktops and using gas or electric convection ovens – have significant non-energy benefits. In the case of induction cooktops, these non-energy benefits are likely a primary driver of the devices' increasing market share. Under current test procedures, the energy savings attributable to induction cooktops result in a very long simple payback.

User behavior is also an important contributor to cooking appliance energy use, with behavioral variations likely to exceed the energy use differences between efficient and inefficient equipment.

6. Refrigerators

This chapter summarizes the refrigerator market and efficiency trends, gathered from manufacturer interviews and secondary research.

6.1. Product Overview

The refrigerator and freezer cooling system is comprised of a compressor that runs when the thermostat calls for cooling (about 80-90% of the time), a condenser made of metal coils that acts as a heat exchanger, a flow control device that meters the flow of refrigerant to the evaporator, and the evaporator (DOE 2011). The low-temperature liquid in the evaporator absorbs heat from its surroundings. Most residential refrigerators also have an automatic defrost system that automatically melts the frost that accumulates in the freezer area (DOE 2011). Refrigerators also have a thermostat to monitor temperature and internal lighting. Some have a dispenser in the door that allow for accessing potable water and ice, called through-the-door (TTD) ice and water service. Three primary components draw energy: the compressor, the condenser fan, and the evaporator fan; lights use a nominal amount of energy. The compressor is the main energy-using component, using up to 90% of the energy consumed by the fridge (LG 2015a).

The level of insulation also affects the overall efficiency of the unit. There are many different sizes, door, freezer, defrost, and TTD configurations of refrigerator-freezers: these configurations affect efficiency specifications.

6.2. Efficiency Specifications

- **Efficiency standards vary depending upon the product class of the refrigerator**. There are 18 product classes and efficiency standards vary by whether the refrigerator has automatic or manual defrost, whether the freezer is top-, bottom-, or side-mounted next to the refrigerator, whether there is through-the-door ice service, and whether or not the unit is compact (DOE 2011).
- The federal minimum refrigerator specification is in its fifth version and has been effective since September 15, 2014 (DOE 2011).
- To qualify for ENERGY STAR certification, the refrigerator or refrigerator-freezer (7.75 cubic feet or larger) must use 9-10% less energy than the federal minimum efficiency standard for its product class (ENERGY STAR 2015c).
- CEE Tier 1 refrigerators also require the unit to use 10% less than the federal minimum efficiency standard while CEE Tier 2 requires a 15% reduction and CEE Tier 3 requires a 20% reduction (CEE 2014).

- The DOE estimates annual unit energy consumption for refrigerator-freezers to be 660kWh/year (Navigant 2014), but baseline refrigerator usage varies with configuration. For example, prior to the 2014 code changes, a top-mount refrigerator-freezer uses an average of 574 kWh per year, while a side-by side refrigerator-freezer with TTD used 881 kWh per year (DOE 2011).

6.3. Market Share

- **The refrigerator market saw a notable increase in ENERGY STAR penetration between 2010 and 2013.** In 2013, ENERGY STAR penetration was 74% of shipped units (ENERGY STAR 2013b), compared with 50% in 2010 (ENERGY STAR 2011).
- **Consumers and retailers expect refrigerators to be ENERGY STAR.** Manufacturers reported that the market is now saturated with ENERGY STAR-certified refrigerators and one stated that “ENERGY STAR is now table stakes for refrigerators.” They said this means that retailers expect manufacturers to have at least three-fourths of their models ENERGY STAR-certified or the retailer will not feature the models on the showroom floor.
  - Interviewees also reported that consumers now expect refrigerators to be ENERGY STAR-certified and this is one reason why retailers require manufacturers to design most of their models to meet the specification.
  - Manufacturers reported that efficient technologies are moving down in price point.

6.3.1. Sales

- In the **United States** in 2013, 9,350,000 refrigerators shipped (Appliance Magazine 2014b).
  - 6,925,000 were ENERGY STAR refrigerators (ENERGY STAR 2014).
  - Market penetration estimate for ENERGY STAR fridges for 2013 is 74% (not including compact products; ENERGY STAR 2014).
- In 2014, 9,660,000 refrigerators shipped in the U.S. (Appliance Magazine 2014b).

6.3.2. Installed Base

- The installed base for the **United States** is estimated to be 117.1 million refrigerators (Navigant 2014).
  - More than 60 million of them are over 10 years old (ENERGY STAR 2015c).

- Over 99% of **California** homes have a refrigerator (DNV GL 2014).
  - 27% have more than one refrigerator or refrigerator-freezer (DNV GL 2014).[6]
  - In California, 53% of refrigerators are estimated to be over ten years old (DNV GL 2014).
  - Half of California homes had a top-freezer configuration in 2012 (DNV GL 2014; Table 6-1).

Table 6-1: Percentage of California Homes with Refrigerator-Freezer Types

FEATURE	2009*	2012
Top-freezer	48%	50%
Side-by-side	37%	36%
Bottom-freezer	7%	13%
TTD ice service		
Yes	36%	Not available
No	63%	Not available

* The other 8% had single-door refrigerator, three or more doors, or a half size refrigerator.

Sources: RECS 2009; DNV GL 2014.

6.4. Supply Chain

- Compressors are an important energy-using component of refrigerators. The compressor manufacturer with the largest global market share is Embraco with 25% of the global market share in 2006 (DOE 2011 Chapter 3).
- Most refrigerators move directly from manufacturers to retailers to consumers (DOE 2011 Chapter 3).
- In 2014, Haier had the largest refrigerator market share (19%), overtaking Whirlpool (Euromonitor 2015b).

6.5. Cost

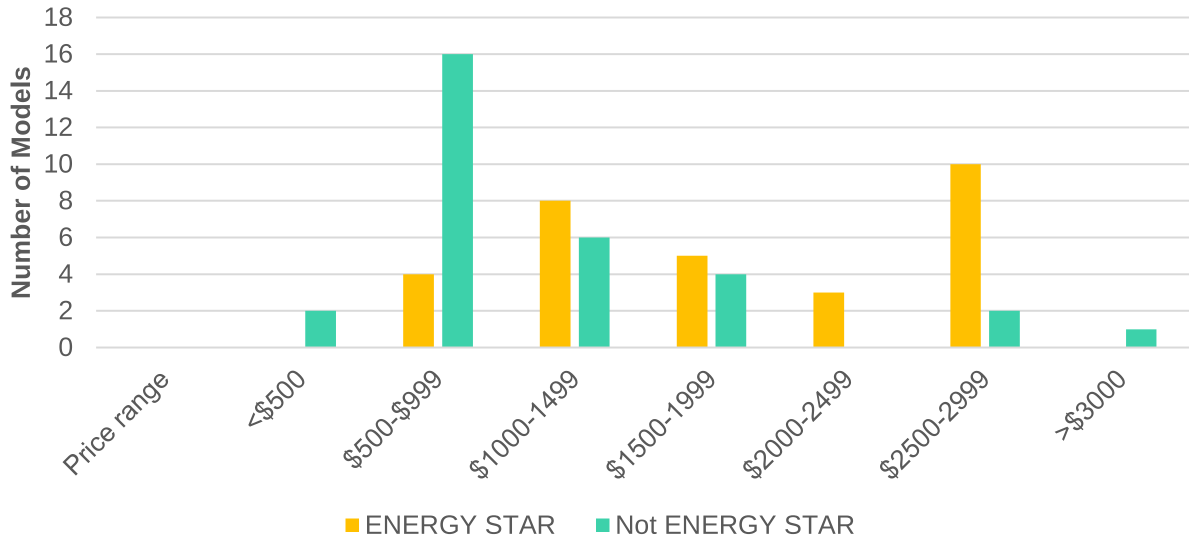
ENERGY STAR availability varies by price point. The price of refrigerator-freezers for the residential market vary substantially, from less than $400 to over $3,000. At price points below $1,000, there are more *non*-ENERGY STAR-certified models available in-store and above $1,000, there are more ENERGY STAR-certified models available in-store (Figure 6-1).[7]

6 Minimal differences across IOUs: 25.5% for PG&E, 29.2% for SCE, and SDG&E in between

7 The selection of the stores began by identifying major appliance retailers and visiting their websites. Only two of the top five retailer websites presented information for in-store availability and ENERGY STAR designation in an accessible format; these

Continued…

Figure 6-1: 2015 Availability of Refrigerators by Price Point in Two California Stores



6.6. Attitudes and Behavior

Consumer purchase decisions and usage behaviors affect efficiency purchases and realized savings.

6.6.1. Consumer Purchase Decisions

- Manufacturers report that consumers expect refrigerators to be ENERGY STAR certified (see Market Share, above).
- A majority of consumers (59%) replace their refrigerator before it fails; however, emergency replacements require immediate decisions. Forty-one percent of refrigerators are purchased because the previous one died or was broken and too costly to repair (AHAM 2015). When a refrigerator fails, it must be replaced immediately as there are no backups for cooling food as there are for washing dishes when a dishwasher fails. Emergency replacement limits the time the consumer has to conduct comparative research on efficiency and causes consumers to purchase immediately-available units, which may not include efficient options (Choi et al. 2009).
- **The refrigerator shapes decision-making for other kitchen appliances.** Since the refrigerator is typically the most expensive kitchen appliance, in major renovations, consumers tend to purchase the refrigerator first and use their remaining budget to purchase other needed kitchen appliances like dishwashers and stoves. Once the consumer chooses their refrigerator, they use its characteristics like brand, finish, and

were Sears and Lowes. The availability of the stores have been added together, which approximates retailer choice, but may include duplicate models.

features to match remaining appliances, simplifying their decision-making for dishwashers, stoves, and microwaves (Efficiency 2.0 2012).

6.6.2. Refrigerator Usage Behaviors

- **Consumers do not usually adjust the factory settings.** Most consumers keep the refrigerator's temperature and humidity dials on the factory setting either because they do not notice the dials or because the factory setting functions well to keep their food cold (Efficiency 2.0 2012).
- **Limiting door-opening does not waste as much energy as cooling hot foods in the refrigerator.** It is commonly understood that each time a consumer opens the refrigerator door, cold air escapes, causing the unit to have to re-cool the interior space. However, much of the coldness of the refrigerator is held by the contents and not the air (Breckenridge 2012; Stamminger et al. 2007). Defrosting frozen food in the refrigerator and properly cooling hot foods before placing them into the refrigerator would result in energy savings (LG 2015b).[8]

6.7. Challenges and Benefits

Cost and technical feasibility are the only challenges manufacturers face in increasing unit efficiency. Similarly, there are few consumer barriers to purchasing efficient refrigerators, besides a moderate upfront cost premium. In addition to energy savings, there are several benefits to the consumer from the use of efficient refrigerators (LBNL 2015):

- **Quieter performance** resulting from efficient compressors and motors
- **More comfortable kitchen environment** from less heat released into kitchen
- **Contents kept colder during power outages** due to improved insulation

6.8. Technical Opportunities to Increase Efficiency

Refrigerator efficiency has increased dramatically since specifications were introduced, and manufacturers report little opportunity for further near-term large efficiency gains within existing refrigerator technology.

- Manufacturers reported little opportunity to improve refrigerator efficiency in the next ten years. They saw diminishing returns for each new technological advancement and described it as "harder and harder" to realize incremental efficiency gains.
- Marginal energy savings can result from changes to many components. Manufacturers spoke about how energy efficiency improvements in refrigerators is a synergistic

8 The evaluation team is unable to locate any studies that quantify the energy impact of hot foods in the refrigerator.

exercise. As one manufacturer stated, "When you tweak one thing, you end up tweaking them all." They cannot realize significant energy savings by altering one component.

- The DOE, in its Roadmap for Next-Generation Appliances from October 2014, identified several refrigerator-related technological research and development opportunities with relatively high technical potential that require additional research (Navigant 2014).

Nevertheless, manufacturers identified several existing or emerging technologies to increase the efficiency of refrigerators. The text below includes information from manufacturer interviews and Table 6-2 includes information on the components' current status, technological barriers, and energy savings potential where known.

- **Advanced compressors:** High-efficiency compressors are already widely installed in refrigerators meeting ENERGY STAR qualification (SBW Consulting 2014).
  - One manufacturer identified variable speed compressors as a near-term opportunity. Another manufacturer publishes on their website whether variable speed compressors are present in refrigerators, demonstrating these types of compressors are already available on the residential market.
  - Dual compressors were another opportunity identified by the manufacturers, as this type of compressor allows for the cooling of defined areas in the refrigerator.
- **Improved insulation:** Manufacturers identified improved insulation as one way to improve energy efficiency of refrigerators.
  - Increasing cabinet insulation makes it difficult to maintain internal capacity and shelf space, which consumers highly value, however.
  - Vacuum-insulated panels may provide a workaround to this issue as they take up less space than traditional insulation. However, manufacturers report that the manufacturing process for vacuum-insulated panels is prohibitively expensive and more research is needed to demonstrate their reliability and longevity in residential appliances (Navigant 2014).
- **Improved mechanics:** Manufacturers are investing in research and development to improve ice-making mechanics and defrost cycles.
- **Efficient LED lighting:** Manufacturers are also looking to switch the lighting inside refrigerators from incandescent bulbs to LED lights.
- **Magnetic refrigeration:** One manufacturer reported developing a cooling system using magnets instead of a chemical refrigerant, but this remained a longer-term opportunity and is not yet ready for the market (estimated market arrival was 2020).

Table 6-2: Technology Opportunities to Increase Refrigerator Efficiency

TECHNOLOGY	CURRENT STATUS	BARRIERS	POTENTIAL ENERGY SAVINGS	TIME UNTIL ON RESIDENTIAL MARKET
Advanced Compressors	On the market, but could be improved	Higher initial cost; compatibility with fluorinated refrigerants; improving reliability.	20%	2-10 years
Vacuum-insulated Panels	Available for commercial and high-end residential refrigerators.	High manufacturing cost; improve reliability; manufacturing not keeping up with demand.	UNK	0-10 years
Magnetic Refrigeration	Proof of concept developed, but prototypes are large and noisy.	High manufacturing cost, size, noise, and reliability.	20%	5-10 years
Improved Ice-making Mechanics	TTD ice and water service is common, but displaces insulation.	Improved design methods needed to reduce heat load of TTD service.	UNK	2-5 years
Efficient LED Lighting	Available in commercial refrigerators and some higher-end residential fridges.	UNK	Low	0-2 years

Sources: DOE 2011; GE 2014

6.9. Manufacturer Perspectives on Utility Collaboration to Promote Efficient Components

One of the research questions the Statewide PLA team had for manufacturers was assessing their interest in promoting efficient compressors through creating a campaign similar to the *Intel Inside* campaign that alerts customers to the unseen "insides" of the product they are purchasing. Manufacturers expressed hesitancy and concern about a program highlighting efficient refrigerator components, and strongly preferred technology-neutral specifications.

- **The sticker should reflect the overall performance of the product instead of the presence of one component.** Manufacturers were concerned that the campaign may be misleading if it only highlights the presence of one component (e.g., high-efficiency compressors) instead of reflecting the overall efficiency of the appliance; one efficient component does not equate to an energy-efficient unit. Furthermore, manufacturers reported that this campaign does not reflect their design process: altering one component requires altering many, and they cannot realize significant energy savings by altering one component.
- **It may have little impact in promoting energy-efficient purchases.** Interviewed manufacturers expressed doubt that such a campaign would increase the priority of energy efficiency for the consumer compared to other considerations like capacity, lighting, and color.

- **There might be a general opportunity to improve awareness and understanding of efficient features.** One manufacturer expressed a positive sentiment around a previous campaign that showed cutaways of old refrigerators to demonstrate how *inefficient* they were. He felt it improved the visibility of important features that the customer does not always see and facilitated the consumers' understanding of the more efficient features in the newer appliances. Other manufacturers reported that consumer understanding of efficient features was low, but questioned whether this type of campaign would alter consumer decision-making.

6.10. Conclusions

In the near term, remaining opportunities to increase refrigerator efficiency are likely to be incremental and based on improvements to insulation or components like compressors. Despite the importance of individual components in energy savings, manufacturers do not see component-focused labels as an effective way to promote more efficient refrigerators. Manufacturers note that changes in one component often require changes across the refrigerator design, and that component-focused labels may have limited influence on consumers, who prioritize factors other than efficiency in their purchase decisions. In the long term, technologies like magnetic cooling or alternate refrigerants may provide opportunities for greater refrigerator energy savings.

Sources

[AHAM] Association of Home Appliance Manufacturers. 2014. As cited in Statistia Inc. 2014. "Automatic Washer and Dryer Shipments in the US 2012-2014, by Month." *http://www.statista.com/statistics/271593/automatic-washer-and-dryer-shipments-in-the-us-since-2009-by-month*.

[AHAM] Association of Home Appliance Manufacturers. 2015. "Early Replacement Program." *Department of Energy Webinar*.

Amberg, Caroline. 2014. "Hygiene Under the Microscope: Microbiology in the Domestic Laundry Settings in Developed and Developing Settings – Challenges and Solutions." *Swissattest*. Dubai: Presentation at Global Hygiene Council Meeting. *http://www.swissatest.ch/files/downloads/e59c90a6e2ad084686ca61a469072109/Hygiene_aspects_in_washing_machines_dubai_e.pdf*.

Appliance Magazine. 2014a. "62nd Annual US Appliance Industry Forecast." as cited in Statista Inc. "Market Share of Appliance Producer Companies in the United States 2008 and Q2 '13." *http://www.statista.com/statistics/296707/market-share-of-appliance-producer-companies-united-states/*

Appliance Magazine. 2014b. "62nd Annual US Appliance Industry Forecast." as cited in Statista Inc. "Refrigerators: Unit Shipments in the US 2005-2017." *http://www.statista.com/statistics/220111/unit-shipments-of-refrigerators-and-freezers-in-the-us*.

[ASAP] Appliance Standards Awareness Project. 2015. "Clothes Washers." *http://www.appliance-standards.org/product/clothes-washers*.

Baldwin, Ron and P. Chan. 2011. "Draft_Cooktop_Life-Cycle_Cost_Spreadsheet" and "Draft_Oven_Life-Cycle_Cost_Spreadsheet." Berkeley, CA: Lawrence Berkeley National Laboratory. *http://www.regulations.gov/#!documentDetail;D=EERE-2006-STD-0127-0122*.

Barry, Keith. 2014. "Electrolux, GE Deal Marks Increased Consolidation." *USA Today*. *http://www.usatoday.com/story/money/2014/09/08/electrolux-ge-deal-marks-increased-consolidation/15277025/*.

Breckenridge, Mary Beth. 2012. "Energy Mythbusting: The Truth about those Energy-Saving Tips." *Phys.org*. *http://phys.org/news/2012-02-energy-mythbusting-truth-energy-saving.html*.

[BPA] Bonneville Power Administration. 2015. "Appliance Standards: How they Interact with Energy Efficiency Programs." *http://www.bpa.gov/EE/Utility/research-archive/Documents/Appliance_Standards_Report.pdf*.

California Energy Commission. 2015. Consumer Energy Center Residential Microwave Oven, from Consumer Guide to Home Energy Savings. *consumerenergycenter.org/residential/appliances/microwaves.html*

[CEE] Consortium for Energy Efficiency. 2014. *High Efficiency Specifications for Refrigerators and Refrigerator-Freezers*. *http://library.cee1.org/sites/default/files/library/11746/CEE_ResidentialRefrigeratorSpecification_15Sep2014.pdf.*

[CEE] Consortium for Energy Efficiency. 2015. "Super Efficient Home Appliances Initiative: Clothes Washer Qualifying Product List." *http://library.cee1.org/sites/default/files/library/9268/2015_March_CEE_ResidentialClothesWashers_web_3-20_version.xlsx*

Choi, Hannah Granade, Jon Creyts, Anton Derkach, Philip Farese, Scott Nyquist, and Ken Ostrowski. 2009. "Unlocking Energy Efficiency in the US Economy." *McKinsey & Company*. *http://www.greenbuildinglawblog.com/uploads/file/mckinseyUS_energy_efficiency_full_report.pdf*.

Consumer Reports. 2014. "Pros and Cons of High-Efficiency Washers." *http://www.consumerreports.org/cro/news/2014/09/the-pros-and-cons-of-high-efficiency-washers/index.htm*.

DNV GL. 2014. *WO21: Residential On-site Study: California Lighting and Appliance Saturation Study (CLASS 2012)*. Calmac Study ID: CPU0095.01. *http://www.calmac.org/publications/2014.11_24_WO21_CLASS_Final_Report_CleanES.pdf*

[DOE] U.S. Department of Energy. 2009. "Final Rule: Energy Conservation Standards for Certain Consumer Products (Dishwashers, Dehumidifiers, Microwave Ovens, and Electric and Gas Kitchen Ranges and Ovens) and for… [Commercial Clothes Washers]." Washington D.C.: National Archives, Code of Federal Regulations 10 CFR Part 430. Federal Register Vol. 74, No. 66. *http://www.regulations.gov/#!documentDetail;D=EERE-2006-STD-0127-0004.*

[DOE] U.S. Department of Energy. 2011. "Technical Support Document for the Final Rule on Residential Refrigerators, Refrigerator-Freezers and Freezers." *http://www1.eere.energy.gov/buildings/appliance_standards/pdfs/refrig_finalrule_tsd.pdf*

[DOE] U.S. Department of Energy. 2012a. "Energy Conservation Program: Energy Conservation Standards for Residential Clothes Washers." Docket # EERE-2008-BT-STC-0019. *http://www1.eere.energy.gov/buildings/appliance_standards/pdfs/rcw_direct_final_rule_5_14_2012.pdf*.

[DOE] U.S. Department of Energy. 2012b. “Technical Support Document: Energy Efficiency Program for Consumer Products and Commercial and Industrial Equipment: Residential Clothes Washers.” *http://www.regulations.gov/#!documentDetail;D=EERE-2008-BT-STD-0019-0047*.

[DOE] U.S. Department of Energy. 2013.*“New Energy Efficiency Standards for Microwave Ovens to Save Consumers on Energy Bills.”* Washington, DC: Energy.gov. *http://energy.gov/articles/new-energy-efficiency-standards-microwave-ovens-save-consumers-energy-bills*

[DOE] U.S. Department of Energy. 2014a. “Energy Conservation Program: Energy Conservation Standards for Residential Clothes Dryers Request For Information.” Docket # EERE-2014-BT-STD-0058. *http://energy.gov/sites/prod/files/2015/03/f20/Clothes%20Dryer%20Standards_RFI.pdf*.

[DOE] U.S. Department of Energy. 2014b. “Rulemaking for Residential Clothes Dryers Test Procedure.” *http://www1.eere.energy.gov/buildings/appliance_standards/rulemaking.aspx/ruleid/54*.

[DOE] U.S. Department of Energy. 2014c. *Test Procedures for Conventional Cooking Products; Supplemental notice of proposed rulemaking and corrections. http://www.regulations.gov/#!documentDetail;D=EERE-2012-BT-TP-0013-0013*

[DOE] U.S. Department of Energy. 2015a. “Energy Conservation Program: Energy Conservation Standards for Residential Conventional Ovens.” Washington, DC: Federal Register Notice of Proposed Rule. *https://www.federalregister.gov/articles/2015/06/10/2015-13764/energy-conservation-program-energy-conservation-standards-for-residential-conventional-ovens#h-18*

[DOE] U.S. Department of Energy. 2015b. “Residential Clothes Dryers.” *http://www1.eere.energy.gov/buildings/appliance_standards/product.aspx/productid/36#recentupdates*.

[DOE] U.S. Department of Energy. 2015c. “Residential Clothes Washers.” *http://www1.eere.energy.gov/buildings/appliance_standards/product.aspx/productid/39*.

Efficiency 2.0. 2012 “Transforming Awareness into Action: Consumer Perceptions of Energy Use in the Chicago Metropolitan Area.” *http://www.igencc.org/sites/default/files/pdfs/EI2_ethnographic_research.pdf*.

Ehrlich, Brent. 2015. “Heat-Pump Clothes Dryers Finally Reach U.S.” Brattleboro, VT: BuildingGreen.com blog. *https://www2.buildinggreen.com/article/heat-pump-clothes-dryers-finally-reach-us*

ENERGY STAR. 2009. *Refrigerator Market Profile*. U.S. Department of Energy: Energy Efficiency and Renewable Energy. Washington, D.C.

ENERGY STAR. 2011. "ENERGY STAR® Unit Shipment and Market Penetration Report Calendar Year 2010 Summary." *https://www.energystar.gov/ia/partners/downloads/unit_shipment_data/2010_USD_Summary_Report.pdf?eb5e-63de*

ENERGY STAR. 2013a. "2013 Emerging Technology Award: Advanced Clothes Dryers." *https://www.energystar.gov/about/awards/awards-archive/2013-emerging-technology-award-advanced-clothes-dryers*

ENERGY STAR. 2013b. "ENERGY STAR® Unit Shipment and Market Penetration Report Calendar Year 2013 Summary." *https://www.energystar.gov/ia/partners/downloads/unit_shipment_data/2013_USD_Summary_Report.pdf?6956-9bc5*

ENERGY STAR. 2014a. "2014 Emerging Technology Award: Advanced Clothes Dryers." *https://www.energystar.gov/about/awards/energy-star-emerging-technology-award/2014-emerging-technology-award-advanced-clothes-dryers*

ENERGY STAR. 2014b. "ENERGY STAR® Unit Shipment and Market Penetration Report Calendar Year 2013 Summary." *https://www.energystar.gov/ia/partners/downloads/unit_shipment_data/2013_USD_Summary_Report.pdf?a003-1af7*

ENERGY STAR. 2015a. "Clothes Washers for Consumers: Product Overview." *https://www.energystar.gov/products/certified-products/detail/clothes-washers*

ENERGY STAR. 2015b. "ENERGY STAR Program Requirements Product Specification for Clothes Washers: Eligibility Criteria Version 7.0." *https://www.energystar.gov/sites/default/files/specs//ENERGY%20STAR%20Final%20Version%207.0%20Clothes%20Washer%20Program%20Requirements.pdf*ENERGY STAR. 2015b. "Clothes Washers for Partners." Archived Tab. Accessed May 29, 2015 from *https://www.energystar.gov/products/certified-products/detail/7604/partners*.

ENERGY STAR. 2015c. "Refrigerators." *https://www.energystar.gov/products/certified-products/detail/refrigerators*.

ENERGY STAR 2015d. "Refrigerators for Partners." Archived Tab. *http://www.energystar.gov/products/certified-products/detail/7602/partners*

[EPA] Environmental Protection Agency. 2015. "News Releases from Headquarters: First Clothes Dryers to Earn EPA's Energy Star Label Now Available Nationwide."

Euromonitor International. 2015a. "Large Cooking Appliances in the US ." http://www.euromonitor.com/large-cooking-appliances-in-the-us/report.

Euromonitor International. 2015b. "Refrigeration Appliances in the US." *http://www.euromonitor.com/refrigeration-appliances-in-the-us/report*.

Firestone, Ryan and Christian Douglass. 2015. "Residential Clothes Washers and Dryers." *Regional Technical Forum: Technical Subcommittee*.

GE (General Electric). 2014. *From Ice Blocks to Compressors to Magnets: The Next Chapter in Home Refrigeration*. *http://pressroom.geappliances.com/news/from-ice-blocks-to-compressors-to-magnets:-the-next-chapter-in-home-refrigeration*

Hagerty, James and Min-Jeong Lee. 2013. "Samsung's Phones Help Sell Home Appliances." *The Wall Street Journal*. *http://www.wsj.com/articles/SB10001424127887323664204578609892263756014*

Hood, James R. 2014. "Supreme Court Lets Moldy Washer Cases Keep on Churning." *Consumer Affairs*. *http://www.consumeraffairs.com/news/supreme-court-lets-moldy-washer-cases-keep-on-churning-022514.html*.

Illinois Energy Efficiency Stakeholder Advisory Group. 2014. *Illinois Statewide Technical Reference Manual: Version 3.0*. *http://ilsagfiles.org/SAG_files/Technical_Reference_Manual/Version_3/Final_Draft/Illinois_Statewide_TRM_Effective_060114_Version_3%200_021414_Final_Clean.pdf*.

J.D. Power. 2014. "Customer Satisfaction Drives Brand Loyalty That Can Translate to More Same-Brand Packages Sold." *Laundry Appliance Satisfaction Study*. *http://www.jdpower.com/sites/default/files/2014108%20KitchenLaundryAppliance_Final_Rev4.pdf*.

Kapner, Suzanne. 2013. "Sears Crucial Appliance Sales Erode." *The Wall Street Journal*. *http://www.wsj.com/articles/SB10001424127887323665504579028371672070930*.

KEMA Inc. 2004. "Residential Refrigerator Recycling Ninth Year Retention Study." Madison, WI. Study ID Nos. 546B, 563.

[LBNL] Lawrence Berkeley National Laboratory. 2004. *"Technical Support Document for Residential Cooking Products (Docket # EE-RM-S-97-700): Volume 2-Potential Impact Of Alternative Efficiency Levels For Residential Cooking Products."* Berkeley, CA: Office of Environmental Energy Technologies Division, Technology and Market Assessment Group. Prepared for DOE Codes and Standards Division

[LBNL] Lawrence Berkeley National Laboratory. 2015. "Non-Energy Benefits of Efficient Refrigerators." *http://energy.lbl.gov/ea/mills/hes_flat_content/0_new_site/nebs/neb_ref.html*

LG. 2015a. *http://www.lg.com/us/kitchen/refrigerator/energy-efficient-refrigerator.jsp*.

LG. 2015b. *http://www.manualslib.com/manual/645973/Lg-Refrigerator-Freezer.html?page=31#manual*.

Li, Angela, Shel Feldman, Lynn Hoefgen, and Thomas Ledyard. 2004. "Beyond Clean: Customer Views of Non-Energy Benefits of Clothes Washers." *http://library.aesp.org/resources/Docuworks/file_display.cfm?id=486*.

Navigant Consulting, Inc. 2014. "Research and Development Roadmap for Next-Generation Appliances." DOE – US Department of Energy, Building Technologies Office. *http://energy.gov/eere/buildings/downloads/research-development-roadmap-next-generation-appliances*

[NREL] National Renewable Energy Laboratory. 2012. *http://www.nrel.gov/extranet/ump/docs/09-14-2012_protocol_comments.xlsx*.

Pennsylvania Public Utility Commission. 2014. Technical Reference Manual. *http://www.puc.pa.gov/pcdocs/1265230.docx*.

[RECS] Residential Energy Consumption Survey. 2009. "Appliances Data." *http://www.eia.gov/consumption/residential/data/2009/#undefined*.

Research Into Action and Energy Market Innovations. 2012. *Program and Technology Review of Two Residential Product Programs: Home Energy Efficiency Rebate (HEER) / Business and Consumer Electronics (BCE)*. Study# SCE0306. *http://www.calmac.org/publications/heer__bce_083012_final.pdf*.

Research Into Action, Apex Analytics. 2015. *Television Initiative MPER #4 Draft Report*. (Submitted, but not published). Portland, OR: Northwest Energy Efficiency Alliance.

SBW Consulting, Inc. 2014. "Workpaper Consulting – Preliminary Engineering Review of Residential Refrigerator/Freezer Compressor Efficiency."

[SCE] Southern California Edison. 2009. "Recycling of Appliances Preventing Continued Use." Work Paper WPSCREAP0007. *SCE Strategic Planning & Technical Services*.

Sebold, Frederick, Alan Fields, Lisa Skumatz, Shel Feldman, Miriam Goldberg, Ken Keating, and Jane Peters. 2001. *A Framework for Planning and Assessing Publicly Funded Energy Efficiency*. Prepared for Pacific Gas & Electric. Study ID PG&E-SW040.

Shelter Analytics. 2014. *Mid-Atlantic Technical Reference Manual: Version 4.0*. Facilitated and Managed by Northeast Energy Efficiency Partnerships. Retrieved May 22, 2015 from *file:///C:/Users/jen/Downloads/Mid_Atlantic_TRM_V4_FINAL%20(1).pdf*.

Stamminger, Rainer, Angelika Suljug, and Anja Hillenstedt. 2007. "Preparatory Studies for Eco-Design Requirements of EuPs." Lot 13: Refrigerators & Freezers. Task 3: Economic and Market Analysis. *http://www.landtechnik.uni-bonn.de/research/appliance-technology/publications/08-01-01-lot-13-domestic-refrigerators-freezers-2*.

The Cadmus Group, Inc. 2013. "Appliance Recycling Program Process Evaluation and Market Characterization." Prepared for *Southern California Edison and Pacific Gas and Electric*. CALMAC Study ID: SCE0337.01.

Wroclawski, Daniel. 2014. "The Great Washer Debate: Are Front-Loaders Really Better?" USA Today. *http://www.usatoday.com/story/tech/2014/10/13/the-great-washer-debate-are-front-loaders-really-better/17204535/*

Appendices

Appendix A. Preliminary Device Prioritization Memo

The goal of the Device Prioritization and Market Transformation Literature Review (Task 1 of the Work Paper Update Project) is to use the RSW and a market transformation literature review to prioritize 10 devices as a potential focus for future residential energy efficiency programs. This document presents the results of subtask 1, in which Research Into Action used the RSW I to identify ten high priority devices based on the size of the installed base, current penetration of ENERGY STAR among new unit sales, and technical potential for energy savings. The output of this task is a list of the ten prioritized devices, including the reasons for their selection. Research Into Action will next conduct a targeted literature review on each of these devices and issue a final prioritization.

A.1. Selection Criteria

Guided by the NMR white paper, the team identified three relevant criteria (or market indicators) for product selection for market transformation programs (note the white paper identifies other criteria that cannot be assessed with data in the RSW). The team identified one market indicator that corresponded with each of these three criteria (Table A-1).

Table A-1: Device Selection Criteria and Methodology

CRITERIA TO QUALIFY FOR MARKET TRANSFORMATION	MARKET INDICATOR THAT WAS UTILIZED
Small savings per transaction, large aggregate savings	ENERGY STAR UEC savings
Market size large enough to justify resources	Statewide household penetration/saturation
Market failures exist	ENERGY STAR market penetration (new unit sales)

In addition to the three market indicators, the team also considered:

- Current degree of market transformation achieved
- Gas versus electric product balance
- Emerging versus established products
- High versus low certainty/data availability

To prioritize the devices, the team used a two-step approach to 1) develop a preliminary list based on product rankings for the three market indicators above; then 2) refine the preliminary list based on existing knowledge and the additional considerations listed above. The primary selection criteria identified 24 possible devices; using the additional considerations and knowledge, the team narrowed the list to ten devices.

Caveat: There are 43 products without information for any of the three primary market indicators, and the team determined, based on prior knowledge, that none of these products met the market transformation eligibility criteria better than the products identified by the ranking methodology. For the 30 products in the RSW I with saturation data only, the team identified video streaming/Over The Top (OTT) products as a potential device for inclusion based on increasing penetration and relatively low per-unit savings. For gas products, the evaluation team used a similar process, but did not develop formal quartile definitions because of the small number of devices listed in the RSW I.

A.2. Devices Selected

Table A-2 presents the proposed list of 10 devices for further research based on the standard selection criteria and additional considerations.

Table A-2: Selected Devices

	DEVICE NAME PROPOSED FOR MARKET TRANSFORMATION	EXPLANATION FROM ANALYSIS OF KEY FACTORS
	Selected Devices - Electric	
1	Computers (laptop and desktop)	Low to moderate per unit UEC savings, moderate to high penetration/saturation, low to moderate 2012 ENERGY STAR penetration
2	Furnace - Fan	
3	Network equipment	
4	Audio/Video receiver/Component audio	
5	Ceiling fan	Moderate UEC savings, moderate penetration/saturation, relatively low 2012 ENERGY STAR penetration
6	Compact audio	
7	Television	Moderate UEC savings, high penetration/saturation, high 2012 ENERGY STAR penetration, ongoing technology evolution
8	Video streaming/OTT device	No ENERGY STAR criteria, low to moderate but increasing penetration/saturation, emerging technology with moderate per-unit savings
	Selected Devices - Gas	
9	Gas furnace	High penetration devices with moderate savings
10	Clothes dryer (gas & electric)	

For comparison, the other devices identified by the standard selection criteria but not selected are presented below (Table A-3), along with explanations why they were not selected.

Table A-3: Other Devices Considered but Not Selected

DEVICE NAME NOT PROPOSED FOR MARKET TRANSFORMATION	EXPLANATION AS TO WHY NOT PROPOSED
Other Priority Devices From Methodology	
Media player/recorder	Relatively high ENERGY STAR penetration, less market innovation
Refrigerator/freezer Stand-alone freezer	Subject of Work Paper update project (will have additional market characterization research performed through that task)
Uninterruptible power supply	Relatively low penetration
Digital photo frame	Relatively small market
Ventilating fan	Relatively low penetration
Room AC	Relatively high ENERGY STAR penetration
Fax	Decreasing penetration
Scanner	Decreasing penetration
Soundbar	May be covered under compact audio
Printer Set top box Display	Excluded due to high penetration of ENERGY STAR in 2012, but do have increasing connectivity trends and technology is evolving
Telephone Dishwasher	Continued high penetration of efficient technology

Appendix B. Key MT Characteristics of Devices and Final Prioritization Memo

This memo summarizes market transformation (MT) opportunities identified for eight key devices of interest to the Pacific Gas & Electric Company's (PG&E) future residential energy efficiency programs. It builds on Research Into Action's memo of July 15 regarding Task 1.1.

B.1. Project Overview

PG&E is seeking to prioritize devices on which to focus future residential energy efficiency programs. To help with this, the team comprising Research Into Action and NMR Group (NMR) have conducted an assessment of the relative priority for market transformation of eight devices for residential use. This work is intended as a brief and preliminary assessment identifying potential market transformation program opportunities to inform further program planning research. It is not a comprehensive review.

The assessment was based on the Residential Solutions Workbook (RSW I) developed by Research Into Action and a targeted market transformation literature review written by NMR. The device prioritization was based on the devices' potential for energy savings, as shown in the RSW I, and suitability for market transformation using the criteria outlined in the 2013 market transformation white paper authored by NMR Group, "A Review of Effective Practices for Planning, Design, Implementation, and Evaluation of Market Transformation Efforts." NMR is a subcontractor to Research Into Action on this task.

This work is divided into four subtasks. In the first subtask, completed July 8, Research Into Action used the RSW I to identify eight high priority devices based on the size of the installed base, current penetration of ENERGY STAR among new unit sales, and technical potential for energy savings. The output of this task was a list of the top eight prioritized devices. In the second through fourth subtasks, NMR conducted a targeted literature review to identify relevant market characteristics for each of the prioritized devices and produced a summary table with characteristics for each device, prioritized the devices, and prepared a short description of the methodology and findings.

The memo of July 8, this memo, and the attached summary worksheet represent all the deliverables associated with Tasks 1.1 through 1.4.

B.2. Methodology

NMR identified reports for the literature review by searching the websites of the four administrators of strategic market transformation programs listed in the market transformation white paper[9] for market characterization studies and related reports addressing any of the eight devices. For those devices for which we were unable to find recent, relevant reports, NMR also searched for studies in the American Council for an Energy Efficient Economy (ACEEE) Summer Study archives, on the ENERGY STAR website, in the Lawrence Berkeley National Laboratory's archives, and on the Northeast Energy Efficiency Partnerships' (NEEP) website. Of the reports we identified, NMR selected a total of 17 (aiming for two per device) to include in the literature review. We based the selection on the age of the report, its comprehensiveness in relation to the information we sought, and our assessment of the quality of the work.

The 2013 market transformation white paper notes that markets that fulfill the following conditions are better suited for market transformation:

- The market is large enough for the savings to justify the resources needed for transformation
- There are significant non-energy benefits (NEBs) from the product, service, or practice
- The savings per transaction are relatively small, but numerous transactions add up to big savings
- The savings are cost-effective over the long term
- There are significant market failures

We carefully reviewed each report, extracted the relevant information available on each of these conditions for the eight devices, and summarized it in the attached table (see last page). We also included in the table supplemental information from each report, such as the geography or markets covered by the reports, market actors identified, other products sold in the same market, market and product barriers, and market/device opportunities. For each device,

- We included in the table an assessment of each of the conditions that make a market more suitable for MT, based on the literature, and overall suitability of the device for a strategic market transformation approach.
- We developed a preliminary, qualitative assessment of the relative promise of each device for resulting in substantial energy savings for the California program administrators, based on the device's potential for energy savings in California from the RSW and on the targeted literature review. Opportunities identified exclude fuel switching.

9 The four administrators were the Northwest Energy Efficiency Alliance, the New York State Energy Research and Development Authority, the Vermont Department of Public Service, and the Massachusetts program administrators and Massachusetts Energy Efficiency Advisory Counsel.

- We summarized our rationale for the assessments as well as the pros and cons associated with the device or market and identified further research that may be needed to help the California Investor Owned Utilities (IOUs) with their decision-making.

In the spreadsheet, we include a link to the citation for each of the reports we reviewed. The literature review also identified gaps in available market characterization information for some of the devices researched. Where no information was available from the reports consulted, the spreadsheet indicates these data were not specified.

B.3. Findings

Our assessments are shown in Table B-1. The assessment of relative promise of each device for resulting in substantial energy savings takes into account the intensity and length of the heating and cooling seasons and the amount of new construction. Where two devices or groups of devices have the same relative promise for a climate, it was not clear from the research which was more promising. This preliminary assessment is based on a targeted literature review and does not take into account all factors relevant to market transformation, such as the vintage of existing devices in the market, early replacement opportunities, or EULs. These will all need to be examined by the IOUs prior to making decisions about these devices.

Table B-1: MT Device Prioritization

DEVICE	SUITABILITY FOR MT	RELATIVE PROMISE FOR SUBSTANTIAL ENERGY SAVINGS	
		Warmer Climates	Colder Climates
High Efficiency Dryers	High	1	2
Streaming OTT, Component Audio, Compact Audio, Network Equipment (addressed as a group through the promotion of smart strips to reduce energy consumption from the overall plug load)	Medium/High	3	3
High Efficiency Furnace and Furnace Fans (addressed together)	Medium	3 (if substantial new construction)	1
High Efficiency Ceiling Fans	Medium/Low	2 (if substantial new construction)	3 (if substantial new construction)

High Efficiency Dryers. High efficiency dryers—especially electric ventless heat pump or condensing dryers—are highly suitable for MT in California for the following reasons:

- The market is large enough, with enough savings opportunities. Although, as of 2012, 48% of California homes had a gas dryer, a substantial number of homes (27%) had an electric dryer. We expect market saturation for high efficiency units to be very low, as these are only just becoming available, and an ENERGY STAR specification does not yet apply.

- There are sizeable non-energy benefits (NEBs) from high efficiency dryers (though this varies by situation).

- The savings per dryer are small, but there are many dryers in the state and they will need to be replaced as they fail.
- While estimates of lifetime savings vary, the literature suggests that heat pump dryers produce cost-effective savings over long run.
- There are significant market failures in that units have been available in Europe for over a decade but are not available in the U.S., and previous testing methods obscured differences in energy use among different standard dryers.

Major market barriers that programs could help to overcome include high first cost compared to standard dryers, lack of awareness of and familiarity with this device, and lack of consumer trust that a heat pump dryer will perform as well as a standard electric dryer. The first ENERGY STAR specification for dryers will go into effect on January 1, 2015, easing the path of program administrators that choose to support this device. IOU program administrators could play an important role in helping to ensure the transformation of the dryer market and accelerate the process through reducing the incremental cost of this device, educating consumers about the device to increase their awareness and overcome the negative perceptions the literature suggests some consumers have of the device, etc.

Dryers should be a more promising source of savings for service territories with higher saturation of electric dryers and warmer climates with fewer opportunities for savings from heating.

High Efficiency Natural Gas Furnaces and Furnace Fans. High efficiency natural gas condensing furnaces with efficient furnace fans are of medium suitability for MT in California for the following reasons:

- The market is likely large enough and has enough savings opportunities. As of 2012, more than 80% of California homes had natural gas furnaces and about 70% had furnace fans. Space heating is a major energy use, accounting for about 40% in U.S. homes. Furnace fans account for one percent of total residential energy use. Nationally, saturation of ENERGY STAR furnaces is about 35%, and per-unit savings range between 12% and 16%.
- There are some NEBs associated with high efficiency furnaces related to comfort, particularly if the unit is replacing an old or ineffective heating source.
- The savings per unit for high efficiency furnaces is relatively large (ideal market transformation opportunities typically have smaller savings per unit).
- The cost-effectiveness of high efficiency furnaces varies by region (length and intensity of heating season) and by installation type (new construction vs. retrofit). However, there are situations where high efficiency furnaces will be cost-effective in retrofit scenarios, depending on the installation complexity, or in warmer climates if the units are sized appropriately for their home heating needs.

- There are notable market failures in that contractors are not well trained in installation of condensing technologies, which is complex. Existing minimum efficiency standards are still low, and it is unclear what future standards will look like or when they will take effect. High efficiency units are not yet cost-effective in regions with shorter heating seasons.

The most recent ENERGY STAR label for furnaces and furnace fans came into effect in 2013, and a federal standard for furnaces fans will take effect in 2019. Both will provide guidance to program administrators who plan to support this product category through program offerings. Program administrators could play a very important role in helping to further transform the market for high efficiency furnaces and furnace fans by providing training and educational support to contractors to ensure quality installations. Program support of this market could also include educational efforts with homeowners to build awareness about savings opportunities and help them know what to look for in a quality installation. Outreach to decision makers in the new construction industry, which is a major target market for efficient furnaces, is also an opportunity for programs. Some states are beginning to see an increase in customers who replace their equipment early, suggesting a retrofit opportunity. NMR recommends that high efficiency furnace fans be marketed alongside high efficiency furnaces to ensure that they are not overlooked and are included in the overall high efficiency furnace package.

Furnaces and furnace fans are naturally more promising for service territories in colder climates.

High Efficiency Ceiling Fans. We assessed high efficiency ceiling fans as medium/low suitability for MT because relatively few of the market conditions that are more suitable for MT hold for this device in California. Specifically,

- The California market is large enough. The market for ceiling fans in California is sizeable, with 57% of homeowners having one or more ceiling fans, and this percentage has been growing. ENERGY STAR ceiling fans account for just 19% of the market share. As newly constructed homes tend to have more ceiling fans installed, we would expect the most promising market to be in new construction.
- While there are associated NEBs (improved comfort through sufficient airflow and more constant temperatures), we would expect these to apply only where ceiling fans are installed for the first time in existing construction, not as a retrofit.
- While high efficiency fans are capable of saving up to 50% of energy use, the savings per fan is small.
- Cost-effectiveness depends on usage behaviors and what the device offsets (replacing an AC unit with ceiling fans, for example). As ceiling fans are used more in warmer climates and new construction, we would expect cost-effectiveness to be greatest for both.
- The literature did not point to any significant market failures.

Major market barriers that programs could help to overcome include incremental cost differential between high efficiency and standard efficiency ceiling fans, and low awareness of energy-efficient options (especially given the low visibility of this product category).

An ENERGY STAR label was introduced for this product category in 2012, which provides guidance to program administrators who plan to support this product category through program offerings. There are MT activities that program administrators could undertake for this product, including but not limited to education and awareness-building efforts with consumers and other market actors to heighten product visibility, and engaging with manufacturers and ENERGY STAR to encourage the production of very high efficiency technologies (e.g., more efficient motors, advanced blade design).

High efficiency ceiling fans are a more promising device in warmer climates and new construction scenarios where the devices can be incorporated into home design in more easily. The long life of standard ceiling fans makes retrofit opportunities a challenge, and fewer cooling degree days make the product less necessary to homeowners.

Streaming OTT, Component Audio, Compact Audio, Network Equipment (Consumer Electronics Devices). As a group, consumer electronics devices (including streaming OTT, component audio, compact audio, and network equipment) are reasonably well suited for MT in California for the reasons listed below. Had there been more information to indicate that energy efficiency efforts for these devices would be cost-effective over the long run or provide substantial NEBs, we would have rated these devices as more highly suited for MT.

- The market is large enough, with enough savings opportunities. The popularity of some consumer electronics equipment, such as streaming OTT devices (e.g., Apple TV) has been growing rapidly in recent years, with a saturation of about 32% in California in 2012. Other fast-growing devices include compact audio (e.g., book shelf audio systems and docking stations), while networking equipment sales have been flattening. Component audio (e.g., DVD/Blu-ray players, speakers, receivers, etc.) appears to be in decline, given competition from new multimedia resources.
- There were no NEBs noted in the literature we reviewed.
- The savings per transaction is very low for each individual device. If looked at as all four devices combined, the devices are ubiquitous and represent a significant opportunity.
- Cost-effectiveness over the long run is unclear for these products. More research is recommended to better understand this opportunity.
- The key market failure for this device category is the lack of clear direction on how to realize energy savings in this diverse, rapidly changing market.

There is a trend towards increasing the efficiency of consumer electronics, with availability of ENERGY STAR-labeled models for many products, but despite these efforts, some device manufacturers may not prioritize energy efficiency. Consumers typically are not aware of the energy consumption of these devices. This represents a challenge, given that energy savings can be highly dependent on consumer behavior or usage settings. Program administrators could play an important role in helping consumers to manage the plug loads for these devices through encouraging the dissemination and use of smart strips or other control devices by consumers. Additional opportunities for programs could involve educating consumers about how behavioral changes can reduce their miscellaneous energy consumption, engaging with ENERGY STAR to encourage new, more efficient standards for more electronic device categories, or encouraging manufacturers to better incorporate efficiency as a design feature.

Device Summary
Spreadsheet 082914

Appendix C. Engineering Review of Residential Clothes Washers Memo

C.1. Introduction

This memo summarizes the Research Into Action team's review (conducted by SBW) of the key inputs and parameters that determine the energy and water savings associated with efficient residential and commercial clothes washers. Our analysis is directed at residential efficiency standards that took effect in March 2015 and commercial standards that took effect January 2013. New EPA ENERGY STAR® and Consortium for Energy Efficiency (CEE) residential standards will take effect to coincide with the new federal standards. The new federal minimum standards will remain in effect until January 1, 2018.

The team submitted to PG&E (the project coordinator) a list of the key parameters involved in the derivation of energy savings. The project coordinator reviewed the list, added additional parameters, and established research priorities for each parameter. The project coordinator also provided its preliminary analysis of energy savings with the new standards (PG&E, 2014). We focused our engineering analysis below on the high priority parameters using the provided inputs as a starting point.[10]

We restricted our investigation to a limited number of sources:

- The Department of Energy's (DOE's) Technical Support Documents (TSDs), rulemakings, and test procedures in support of the federal standards on residential and commercial minimum clothes washer efficiency
- CEE and ENERGY STAR specifications and publications (CEE, 2015), (ENERGY STAR, 2014b), (ENERGY STAR, 2014a)
- A small number of studies and websites

In this draft, we have added a more complete analysis of top-loading washers.

C.2. Recommendations

At the project coordinator's direction, we did not undertake a review of all parameters involved in the derivation of energy savings, nor did we evaluate the correctness of the general DOE methodology. We did review certain key parameters as described below.

10 Our analysis and memo were completed prior to the release of the California Statewide Work Paper on High Efficiency Clothes Washers, dated May 19, 2015 (PGECOAPP127 R1).

C.2.1. Measure Specification

We identified four possible measure groups for consideration, as indicated in the following tables.

Table C-1: Standard Residential Front-loading Units

Measure type	Standard residential
Measure variants	3 variants, based on efficiency tier
Sector	Residential
Segment	SF/MF/MH
Delivery mechanism	Down/Mid/Upstream
Measure application type	Replace on Burnout (ROB)
Machine specifications	Capacity > 2.5 cubic feet
	Front loading

TIER	IMEF	IWF
ENERGY STAR/CEE Tier 1	2.38	3.7
ENERGY STAR Most Efficient/CEE Tier 2	2.74	3.2
CEE Tier 3	2.92	3.2

Table C-2: Standard Residential Top-loading Units

Measure type	Standard residential
Measure variants	3 variants, based on efficiency tier (Note: currently a small number meet ESME; no available products meet Tier 3)
Sector	Residential
Segment	SF/MF/MH
Delivery mechanism	Down/Mid/Upstream
Measure application type	Replace on Burnout (ROB)
Machine specifications	Capacity > 2.5 cubic feet
	Top loading

TIER	IMEF	IWF
ENERGY STAR	2.06	4.3
ENERGY STAR Most Efficient/CEE Tier 2*	2.76/2.74	3.5/3.2
CEE Tier 3	2.92	3.2

* ENERGY STAR and CEE differ slightly in their efficiency levels

Table C-3: Commercial Front-loading Units

Measure type	Commercial
Measure variants	2 variants, based on segment
Sector	Commercial
Segment	Multifamily common area/Laundromat
Delivery mechanism	Down/Mid/Upstream
Measure application type	Replace on Burnout (ROB)
Machine specifications	Capacity ≤ 6.0 cubic feet Front loading Soft mount

TIER	MEF_{J1}	$IMEF_{J2}$	WF
ENERGY STAR	2.2	1.8	4.5

* J1 and J2 refer to the DOE Test Procedure Appendices J1 and J2. J2 is the newer version which defines IMEF and also a revised MEF. ENERGY STAR is defined in terms of the J1 Test Procedure. The 2014 TSD Table 5.4.3 provides the translation to J2 metrics

Table C-4: Commercial Top-loading Units

Measure type	Commercial
Measure variants	2 variants, based on segment
Sector	Commercial
Segment	Multifamily common area/Laundromat
Delivery mechanism	Down/Mid/Upstream
Measure application type	Replace on Burnout (ROB)
Machine specifications	Capacity ≤ 6.0 cubic feet Top loading Soft mount

TIER	MEF_{J1}	$IMEF_{J2}$	WF
ENERGY STAR	2.2	1.8	4.5

C.2.1.1. Commercial Specification Notes

We restricted our investigation to those machines covered by DOE regulations, with the exception of machine capacity. DOE defines commercial washers as a soft-mounted machine with capacities as follows (DOE, 2010):

1. For horizontal-axis clothes washers, is not more than 3.5 cubic feet; and
2. For vertical-axis clothes washers, is not more than 4.0 cubic feet.

The ENERGY STAR specification allows machines with capacities up to 6.0 cubic feet. Since many available washers are larger than the DOE definition, and since more efficient washers tend to be larger, we recommend including machines up to the ENERGY STAR capacity limit.

We also restricted our investigation to those facility types for which the DOE provides estimates of the number of wash cycles per year. These are multi-family common areas and laundromats. A study by the American Council for an Energy-Efficient Economy (ACEEE) found significant energy savings potential for machines and facility types outside these bounds (Cluett, Amann, Chou, & Osann, 2013). Estimating savings for situations outside the DOE's scope of work would probably require primary research.

C.2.2. Baseline Specification

The baseline is defined by federal minimum standards (DOE, 2010) for residential (DOE, 2012c), and commercial (DOE, 2014) washing machines. Energy savings are derived using the Modified Energy Factor (MEF), or Integrated Modified Energy Factor (IMEF), Table C-5. Water savings are based on the Integrated Water Factor (IWF), or the Water Factor (WF).

Table C-5: Baseline Clothes Washer Specifications*

TYPE	IMEF	MEF_{J1}	MEF_{J2}	IWF	WF
Residential front-loading, capacity > 2.5 cubic feet	1.84	NA	NA	4.7	NA
Residential top-loading, capacity > 2.5 cubic feet	1.29	NA	NA	8.4	NA
Commercial top-loading	NA	1.6	1.15	8.9	8.5
Commercial front-loading	NA	2.0	1.65	4.5	5.5

* Derived from Federal Standards for Clothes Washers.

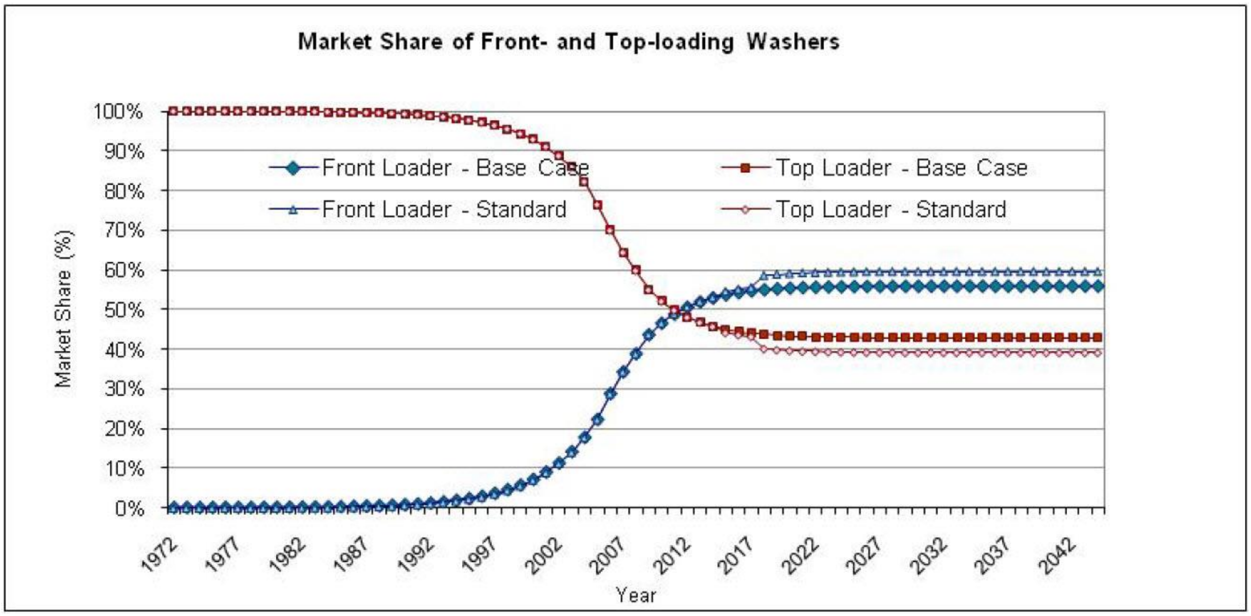
C.2.3. Saturations of Front and Top Loading Washers

C.2.3.1. Residential

The DOE considers front and top loading washers to provide significantly different functionality, and as such, to be distinct classes of appliance. Separate federal and ENERGY STAR standard apply to each category.

As shown in Figure C-1, the 2012 TSD (Chapter 9) forecasts that during the 2015-2017 timeframe, the saturation of front-loading washers would be 55% (DOE, 2012b). We do not have current market data to update the forecast. However, a better forecast estimate would incorporate up-to-date Association of Home Appliance Manufacturers (AHAM) shipment data, but the split may change following the introduction of new standards in March 2015.

Figure C-1: Projected Saturations of Front- and Top-loading Washers*



* From 2012 TSD Figure 9.3.5.

C.2.3.2. Commercial

For commercial washers, in 2010 DOE estimated the fraction of top-loading washers at 70% (DOE, 2010). Recent shipment data from AHAM, cited in the 2014 commercial TSD (DOE, 2014) show that this trend has continued, as seen in Table C-6.

Table C-6: AHAM Data on Shipments of Commercial Washers*

YEAR	SHIPMENTS (000'S)			FRONT-LOAD PERCENTAGE
	Total	Top-Load	Front-Load	
2010	164	104	60	37%
2011	161	107	54	34%
2012	173	120	53	31%
2013	206	151	55	27%

* Taken from 2014 commercial TSD Table 3.9.2.

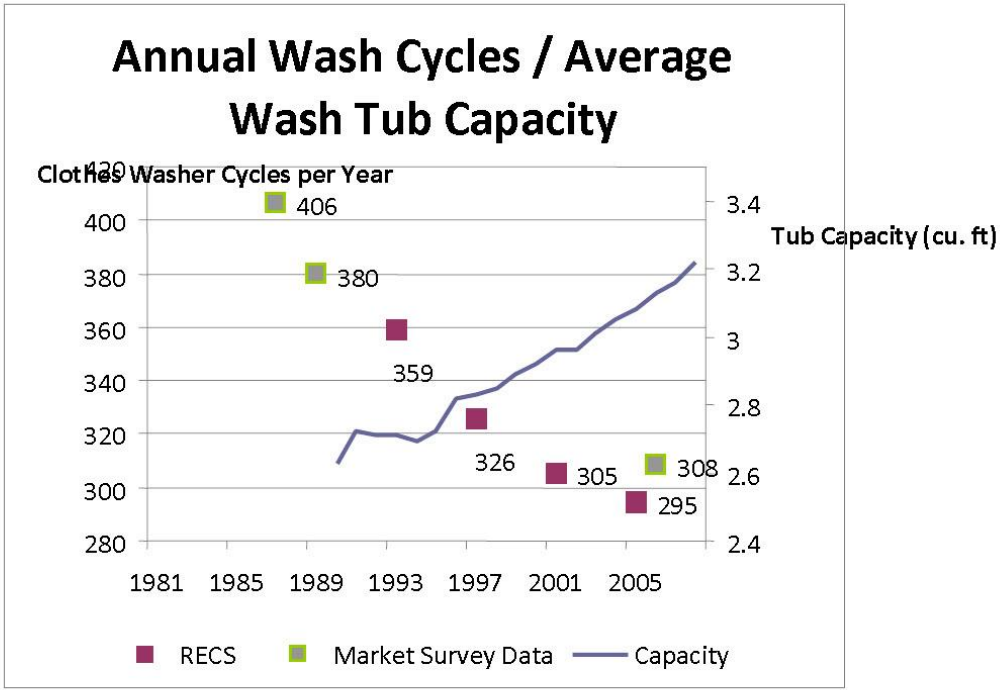
We do not have data for California shipments. The team's recommendation for the baseline split of top-loading/front-loading washers is 70/30.

C.2.4. Volume of clothes washed per year

C.2.4.1. Residential

The DOE reported that the average number of residential loads washed per year was 295 in 2005 (DOE, 2012b). They also noted that the number of loads washed has been decreasing as the average washer capacity has been increasing, as shown in Figure C-2.[11]

Figure C-2: Trends in Washer Usage and Capacity



Rather than standardizing on the number of loads washed, we recommend standardizing on the annual volume of clothes washed. This is an important parameter because more efficient washers are usually larger. As discussed below, we make assumptions about the capacity of more efficient washers, and we assume that fewer loads are done in larger washers. Based on the available DOE data, we estimate the average annual volume of laundry was 295 × 3.1 cubic feet (915 cubic feet), derived from the figure above. We assumed that all loads were full loads, which is probably not an accurate assumption, but all loads in the smaller washer were probably not full either. If we assume that both baseline and efficient-case loads were, on average, three-quarters of capacity, rather than full loads, savings would change by less than 5%. In the absence of data, we believe the full load assumption is reasonable to estimate the number of loads washed for various size machines.

[11] From chapter 7 of the 2012 TSD.

C.2.4.2. Commercial

We do not have the data relating commercial washer capacity to efficiency level that we have for residential washers. Tables 5.6.1 and 5.6.2 in the 2014 TSD show the capacities of a small number of tested washers. For top-loading washers, capacities ranged from 2.9 to 3.5 cubic feet, with the more efficient units being smaller. For front-loading washers, capacities ranged from 2.8 to 3.6 cubic feet, with no clear trend between capacity and efficiency.

In chapter 7 of the 2014 TSD, tables are presented showing MEF vs. energy usage. Washer capacity can be derived from these tables as shown below.

Table C-7: Front-loading Commercial Washer Efficiency vs. Capacity

MEF_{J2}	DERIVED VOLUME (CUBIC FEET)
1.65	2.80
1.80	2.89
2.00	2.90
2.20	3.60

* Taken from 2014 commercial TSD Table 7.2.3.

Table C-8: Top-loading Commercial Washer Efficiency vs. Capacity

MEF_{J2}	DERIVED VOLUME (CUBIC FEET)
1.15	3.09
1.35	3.10
1.55	3.30

* Taken from 2014 commercial TSD Table 7.2.2.

The team's judgment is that meeting the new standards will involve increasing washer capacity, and we recommend basing the washer capacity parameter on the chapter 7 tables.

The DOE (Section 7.3 of the 2014 TSD) has derived new estimates for the number of cycles per year for commercial washers as shown in Table C-9 (DOE, 2014). These values were derived from studies going back to 1999. We derived the annual volume of clothes washed by assuming a 70/30 split of top to front loaders, and assuming that the tub volumes corresponded to the smallest sizes reported in the tables above.

Table C-9: Commercial Cycles per Year and Annual Volume of Clothes Washed per Year

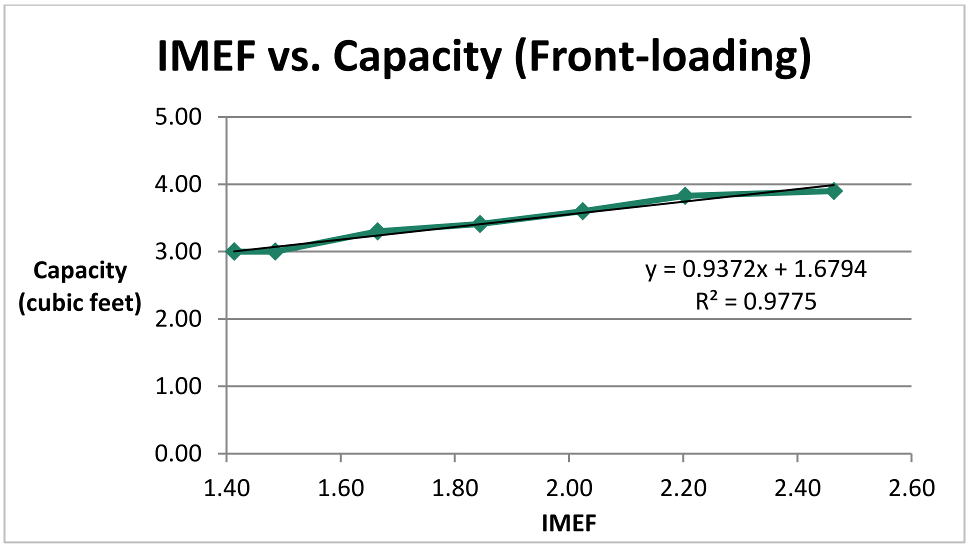
	MULTIFAMILY	LAUNDROMAT
Number of loads	1095	1497
Annual volume (cubic feet)	3291	4499

C.2.5. Capacity of Measure Washer

C.2.5.1. Residential

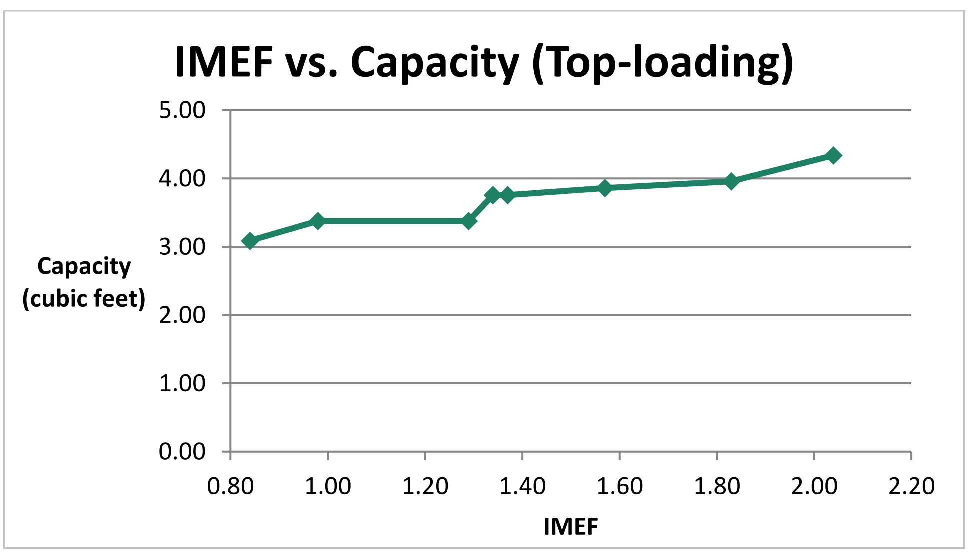
As shown in Figure C-3, based on TSD Table 7.2.2 in the 2012 TSD for front-loading washers, average washer size increases with washer efficiency. Further, as the DOE noted in the 2012 TSD chapter 5, increasing clothes washer capacity is one way to increase the energy factor.

Figure C-3: Front-loading Washer Capacity Increases with Efficiency



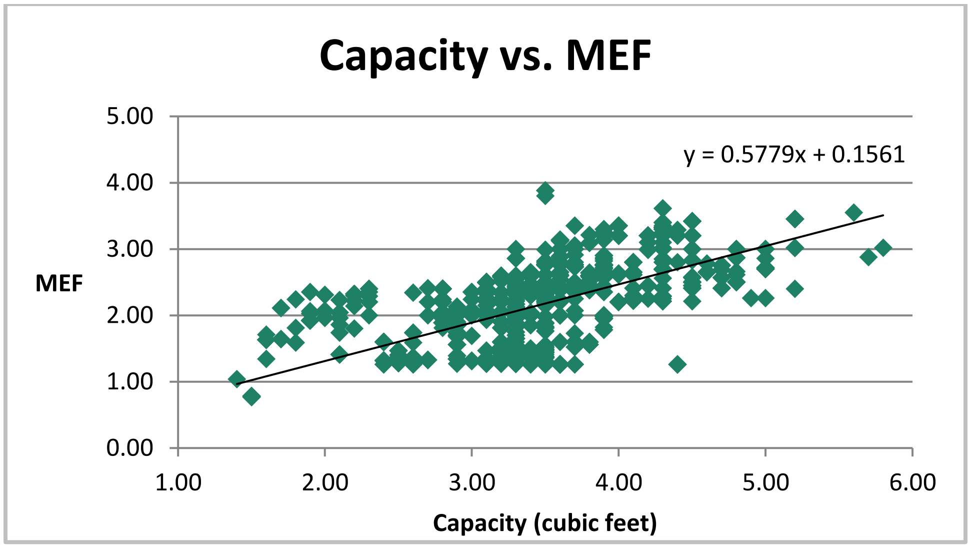
The trend is similar for top-loading machines, based on TSD Table 7.2.1, as shown below.

Figure C-4: Top-loading Washer Capacity vs. Washer Efficiency



Actual energy factors are compared with machine capacity in Figure C-5, from the California Energy Commission (CEC) appliance database in September 2014. These data reinforce the relationship between increasing MEF and increasing capacity.

Figure C-5: CEC Appliance Data MEF vs. Capacity



For front-loading washers, we derived average sizes for the three measure tiers by linear extrapolation from Figure C-3 above based on the table provided by DOE. Extrapolated values are shown Table C-10. The assumed number of loads per year decreases with this value in order to achieve the annual volume of clothes washed noted above.

Table C-10: Capacity of Front-loading Measure Washers by Tier

TIER	CAPACITY (CUBIC FEET)	ANNUAL LOADS
ENERGY STAR/CEE Tier 1	3.91	234
ENERGY STAR Most Efficient/CEE Tier 2	4.25	215
CEE Tier 3	4.42	207

For top-loading washers, the ENERGY STAR washer efficiency level is very close to DOE level 8 in TSD Table 7.2.1. We assumed the washer capacity for the ENERGY STAR washer to be the same as the level 8 capacity shown in Figure C-4, as seen in the table below. The small number of washers that meet the ESME standard have capacities of 4.9 cubic feet or larger (*https://data.energystar.gov/Active-Specifications/ENERGY-STAR-Most-Efficient-Clothes-Washers/d36s-eh9f*?).

Table C-11: Capacity of ENERGY STAR Top-loading Measure Washers

TIER	CAPACITY (CUBIC FEET)	ANNUAL LOADS
ENERGY STAR	4.34	211

C.2.5.2. Commercial

For both top and front-loading washers, we derived capacities for the measure washers using Tables 7.2.2 and 7.2.3 in the 2014 TSD. These tables provide the MEF and the energy consumption per cycle, as shown more fully in Section C.2.7.3. Machine capacity is a direct calculation from these two parameters. The assumed number of loads per year decreases with this value in order to achieve the annual volume of clothes washed noted above.

Table C-12: Capacity of Commercial Measure Washers

TYPE	CAPACITY (CUBIC FEET)	LAUNDROMAT ANNUAL LOADS	MULTI-FAMILY ANNUAL LOADS
DOE base values	3.01	1497	1095
Baseline Front-loading	2.80	1609	1177
Baseline Top-loading	3.09	1469	1075
ENERGY STAR Front-loading	3.08	1460	1068
ENERGY STAR Top-loading	3.39	1326	970

C.2.6. Energy Factor and Water Factor of Measure Washer

C.2.6.1. Residential

For calculating savings, the IMEF, and the IWF of the efficient washer would ideally be the market average of washers sold within the measure tier. However, with new standards taking effect in March 2015, we expect the market to change substantially during 2015. Therefore, we recommend using the efficiency levels directly from the tier specifications, as shown in the measure specification above. The accuracy of the estimated savings could be improved by updating this measure in early 2016, based on the actual energy factors of units shipped.

C.2.6.2. Commercial

For commercial washers, the federal standards have been in effect since January 2013. AHAM shipment data show the following breakdown for front-loading washers by efficiency level (DOE, 2014).

Table C-13: Distribution of Front-Loading Units Shipped by Efficiency Level*

EFFICIENCY BINS			MARKET SHARE (%)			
MEF_{J1}	MEF_{J2}	WF	2010	2011	2012	2013
< 1.72		> 8.0	2%	0%	0%	0%
1.72		8	1%	0%	0%	0%
1.8		7.5	1%	0%	0%	0%
2	1.65	5.5	28%	28%	30%	0%
2.2	1.8	5.1	68%	34%	20%	31%
2.4	2.0	4	0%	38%	50%	69%
2.6	2.2	3.7	0%	0%	0%	0%

* 2014 commercial TSD Table 3.9.5.

All front-loading washers shipped in 2013 met the ENERGY STAR energy efficiency level (MEF 2.2), and the great majority met the ENERGY STAR water savings level (WF 4.5). We recommend that the MEF and WF for the commercial measure washer be the weighted average of the 2013 values shown in the table from the 2014 TSD.

Table C-14: Efficiency Levels for the Front-loading Measure Washer, for Savings Estimation Purposes

2013 SHIPMENTS WEIGHTED AVERAGE VALUES	
MEF_{J1}	2.34
WF	4.34
MEF_{J2}	1.94
IWF	4.49

For top-loading washers, the number shipped in 2013, which met the ENERGY STAR efficiency level, is so negligible that we recommend simply using the efficiency level directly from the measure specification.

C.2.7. Energy Use Breakdown

C.2.7.1. Residential Front-loading

The 2012 TSD shows how energy is used in a wash/dry cycle, according to the energy factor of the washer (Tables 7.2.1 and 7.2.2). The tables do not extend to the ENERGY STAR and CEE tiers scheduled to take effect in 2015. We extended the tables using assumptions described below. We determined the capacity of efficient washers using the approach described above. The overall energy use per cycle is determined by dividing the capacity by the stipulated IMEF. We estimate that the majority of the reduction in the energy factor is due to increased capacity of washers rather than decreases in energy use per wash/dry cycle.

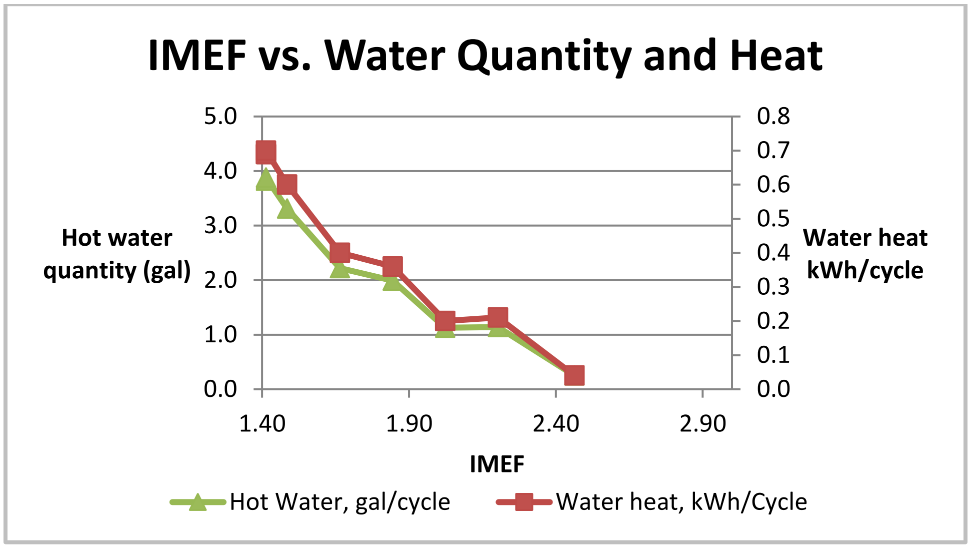
Table C-15: Front-loading Extended Energy Use Breakdown per Cycle

DOE EFFICIENCY LEVEL	MEF	IMEF	VOLUME (CUBIC FEET)	ENERGY USE (KWH/CYCLE)			TOTAL ENERGY USE (KWH/ CYCLE)	HOT WATER (GAL/ CYCLE
				Machine	Dryer	Water Heat		
0	1.72	1.41	3.0	0.113	1.31	0.69	2.12	3.86
1	1.72	1.41	3.0	0.113	1.31	0.69	2.12	3.82
2	1.72	1.41	3.0	0.113	1.31	0.70	2.12	3.88
3	1.8	1.49	3.0	0.113	1.31	0.60	2.02	3.31
4	2	1.66	3.3	0.163	1.42	0.40	1.98	2.22
Residential minimum standard (2015)	2.2	1.84	3.4	0.154	1.34	0.36	1.85	1.99
6	2.4	2.02	3.6	0.164	1.41	0.20	1.78	1.13
7	2.6	2.20	3.8	0.167	1.37	0.21	1.74	1.14
8	2.89	2.46	3.9	0.155	1.38	0.04	1.58	0.25
ENERGY STAR/CEE Tier 1		2.38	3.9	0.160	1.38	0.09	1.64	0.54
ENERGY STAR Most Efficient/CEE Tier 2		2.74	4.2	0.150	1.36	0.04	1.55	0.25
CEE Tier 3		2.92	4.4	0.130	1.34	0.04	1.51	0.25

Water Heat

As shown in the chart below, we believe it will be hard to reduce the water heating portion of the cycle below the current minimum determined by the DOE (DOE efficiency level 8, IMEF = 2.46). Since the ENERGY STAR IMEF is between levels 7 and 8, we estimated the water heating energy for ENERGY STAR/CEE Tier 1 by linear interpolation between levels 7 and 8. At level 8, just one quart of hot water is assumed per average cycle. Beyond level 8, we assumed no change in water heat.

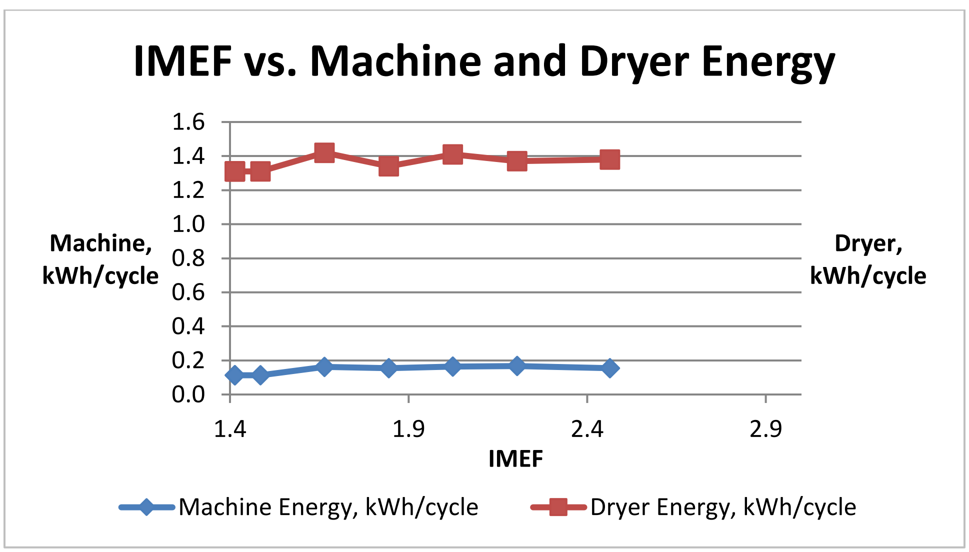
Figure C-6: Variation in Water Heating Energy with Energy Factor



Machine Energy

Washing machine energy usage has remained relatively flat with decreasing energy factors, as shown below. We estimated the CEE Tier 1 usage in Table C-15 by linear interpolation and assumed that a small decrease of 0.03 kWh/cycle is possible with a more efficient motor in CEE Tier 3.

Figure C-7: Washer and Dryer Energy Trend



Dryer Energy

Dryer energy has remained flat with increasing energy factor. We estimated the CEE Tier 1 usage in Table C-15 by linear interpolation and assumed that manufacturers would be able to wring a slight decrease of 0.04 kWh/cycle in CEE Tier 3 dryer energy.

C.2.7.2. Residential Top-loading

For top-loading washers, the highest tier modeled by the DOE (shown in the 2012 TSD Table 7.2.1) has an efficiency level (IMEF 2.04) very close to the ENERGY STAR level (IMEF 2.06). We extended the energy use breakdown table by simply assuming the lowest energy use for each component from the DOE-tested models. The resultant total energy consumption matches that calculated according to IMEF and machine capacity.

Table C-16: Top-loading Extended Energy Use Breakdown per Cycle

DOE efficiency level	MEF	IMEF	VOLUME (CUBIC FEET)	ENERGY USE (KWH/CYCLE)			TOTAL ENERGY USE (KWH/ CYCLE)	HOT WATER (GAL/ CYCLE
				Machine	Dryer	Water Heat		
Baseline	1.26	0.84	3.09	0.279	2.16	1.24	3.68	6.90
1	1.40	0.98	3.38	0.281	2.43	0.74	3.45	4.13
2	1.72	1.29	3.38	0.228	1.69	0.69	2.62	3.85
3	1.80	1.34	3.76	0.082	1.41	1.26	2.81	7.02
4	1.80	1.34	3.76	0.082	1.41	1.26	2.81	7.02
5	1.80	1.37	3.76	0.08	1.41	1.25	2.74	4.92
6	2.00	1.57	3.86	0.082	1.38	0.99	2.46	5.50
7	2.26	1.83	3.96	0.077	1.41	0.67	2.16	3.74
8	2.47	2.04	4.34	0.082	1.39	0.66	2.13	3.67
ENERGY STAR		2.06	4.34	0.077	1.38	0.66	2.11	3.67

C.2.7.3. Commercial

We base our estimates of commercial energy use breakdown on the 2014 TSD, Tables 7.2.2 and 7.2.3, as shown below. Values for the measure washer were derived by linear extrapolation from the DOE table values.

Note that the use of these tables is problematic. Total energy consumption for the front-loading level 3 washer is greater than the consumption of the level 2 washer. DOE reports that dryer energy consumption increased, even though the RMC decreased. Water heating energy also increased. This makes sense based on the larger capacity of the level 3 washer, as noted above. Annual consumption is still lower for the level 3 washer, if we allow fewer annual cycles, as recommended here.

However, the DOE makes no mention of a reduced number of annual cycles. To make matters worse, the DOE reports annual consumption, in Tables 7.3.2-7.3.5. We are unable to understand how they derive these annual totals. For instance, in Table 7.3.4, total annual consumption for the level 2 washer would be 662 kWh/year. At 1095 cycles per year, per cycle consumption would be 0.6 kWh. Their table, however, shows per cycle consumption to be 1.45 kWh.

The team's recommendation is to ignore Tables 7.3.2-7.3.5, and to base annual consumption on the combination of a constant annual volume of clothes washed and the MEF.

Table C-17: Front-loading Washer Energy Use Breakdown*

LEVEL	MEF_{J2} CF/KWH/CYC	MACHINE KWH/CYC	DRYER KWH/CYC	WATER HEAT KWH/CYC
0 (Baseline)	1.65	0.110	1.26	0.33
1	1.80	0.080	1.19	0.34
2	2.00	0.100	1.16	0.19
3	2.20	0.070	1.30	0.27
Measure	1.94	0.089	1.229	0.275

* Taken from Table 7.2.3 of 2014 TSD for front-loading washers, interpolated for measure washer.

The top-loading washer also shows an increase in dryer energy from the level 1 to the level 2 washer. Values for the baseline and measure washer were derived by linear extrapolation from the existing values.

Table C-18: Top-loading Washer Energy Use Breakdown*

LEVEL	MEF_{J2} CF/KWH/CYC	MACHINE KWH/CYC	DRYER KWH/CYC	WATER HEAT KWH/CYC
0 (Baseline)	1.15	0.220	2.08	0.39
1	1.35	0.210	1.58	0.51
2	1.55	0.100	1.62	0.41
Measure	1.80	0.089	1.324	0.472

* Derived from Table 7.2.2 of 2014 TSD for top-loading washers

To derive a weighted average baseline washer, the energy use breakdown values for top-loading and front-loading could be combined using the front/top saturation values reported above.

C.2.8. Water Usage

C.2.8.1. Residential

Annual water consumption is a direct calculation using parameters derived above and provided by DOE (DOE, 2012b). Table C-19 summarizes these values. The saturations of baseline washer types and the IWF values were described above. The capacities of the baseline washers are provided in the 2012 TSD Chapter 7. The derivation of the capacities of the measure washers was described in Section C.2.5.1. The number of loads is based on the annual volume of clothes parameter described in Section C.2.4. Annual usage is the product of IWF, capacity, and number of loads.

Table C-19: Derivation of Annual Water Usage

CASE	WASHER TYPE	SATURATION	IWF GAL/CF/ CYC	CAPACITY CUBIC FEET	NUMBER OF LOADS	ANNUAL USAGE GAL/YEAR
Baseline	Front-loading	55%	4.7	3.41	268	4298
	Top-loading	45%	8.4	3.38	271	7682
	Average					5821
ES/ Tier 1	Front-loading		3.7	3.91	234	3384
ESME/ Tier 2	Front-loading		3.2	4.25	215	2926
Tier 3	Front-loading		3.2	4.42	207	2926

C.2.8.2. Commercial

We base our estimates of commercial water use for both baseline and measure washers on the 2014 TSD, shown for front-loading washers in Table C-20. Note that, according to the TSD, water use per cycle increases between levels 2 and 3, even as the IWF decreases. The explanation is that the machine capacity also increases. Annual savings depend on the assumption that the annual number of loads washed will decrease as the machine size increases. The annual number of cycles was derived as explained in Section C.2.4.2.

The baseline IWF is the federal standard level. The measure IWF is the average of machines shipped that meet the measure standard, based on AHAM data.

Table C-20: Water Use for Front-Loading Washers

LEVEL	IWF GAL/CU.FT	MACHINE CAPACITY CU.FT.	WATER USE GAL/CYC	ANNUAL CYCLES, MF	ANNUAL USE, GAL, MF	ANNUAL CYCLES, LAUNDRY	ANNUAL USE, GAL, LAUNDRY
0	5.2	2.80	14.5	1177	17,112	1,609	23,394
1	4.5	2.89	13.0	1138	14,809	1,555	20,245
2	4.1	2.90	11.9	1135	13,492	1,551	18,446
3	3.9	3.60	14.0	914	12,834	1,249	17,546
Baseline	5.2	2.80	14.5	1177	17,112	1,609	23,394
Measure	4.49	3.08	13.8	1068	14,770	1,460	20,193

* Taken from Table 7.2.3 of 2014 TSD.

For top-loading washers, the baseline IWF is the federal standard level, and the measure IWF is the ENERGY STAR level. Machine capacity also increases as the IWF decreases.

Table C-21: Water Use for Top-Loading Washers

LEVEL	IWF GAL/CU.FT	MACHINE CAPACITY CU.FT.	WATER USE GAL/CYC	ANNUAL CYCLES, MF	ANNUAL USE, GAL, MF	ANNUAL CYCLES, LAUNDRY	ANNUAL USE, GAL, LAUNDRY
0	8.9	3.09	27.5	1063	29,288	1,454	40,040
1	8.8	3.10	27.3	1062	28,959	1,451	39,590
2	6.9	3.30	22.8	998	22,706	1,364	31,042
Baseline	8.9	3.06	27.3	1075	29,288	1,469	40,040
Measure	4.5	3.39	15.3	970	14,809	1326	20,245

* Taken from Table 7.2.2 of 2014 TSD.

C.2.9. Commercial Gas/Electric Saturations

The Multi-housing Laundry Association (MLA) estimates 36% of dryers are electric in multi-family common areas (MLA, 2014). DOE estimates 40% of commercial dryers are electric (DOE, 2014). The California residential survey (RASS) (CEC, 2009) found that 55% of dryers in multi-family environments were electric. While RASS was not examining common areas specifically, we recommend using this value.

For water heat, in Laundromats, DOE estimates 100% gas; in multi-family, (CEC, 2009) found 96% gas hot water. We recommend using this RASS value.

C.2.10. Commercial Water Temperature

We found one jurisdiction, Los Angeles County, which apparently requires a hot water temperature of 140°F. We found this reported in an online forum for Laundromat owners (CLA, 2014) and mentioned in an evaluation of commercial laundry savings in Southern California (Sullivan, Parker, & Pugh, 2008). We could find no other references to code restrictions on water temperature. DOE discusses lower hot water temperatures as a means to save energy, but notes that this measure has met resistance from manufacturers and commercial operators (DOE, 2014). We recommend continuing to use the temperatures assumed in the DOE derivation of savings.

C.2.11. Other Parameters

For the parameters listed below, we recommend no change from the existing PG&E Work Paper values.

- Gas/Electric washer/dryer saturations - Residential
- Interactive effects

- Electric to gas conversion efficiency
- Dryer usage factor
- Fraction of loads washed at various temperatures
- Cold water temperature
- Hot water temperature
- Water and wastewater treatment savings
- Coincident Diversity Factor (DF) (Peak factor) (watts/kWh savings)
- Load shape

C.3. Works Cited

CEC. (2009). *CA Statewide Residential Appliance Saturation Study*. Retrieved from Kemainc.com: https://websafe.kemainc.com/RASS2009/Default.aspx

CEE. (2015, March). *Clothes Washer Specifications*. Retrieved from Consortium for Energy Efficiency: http://library.cee1.org/sites/default/files/library/9268/2015_March_CEE_ResidentialClothesWashers_web.xlsx

CLA. (2014). *Discussion Forum*. Retrieved from Coin Laundry Association: http://www.coinlaundry.org/communities/community-home/viewthread/?GroupId=43&MID=2182&tab=digestviewer

Cluett, R., Amann, J., Chou, B., & Osann, E. (2013). *Saving Energy and Water through State Programs for Clothes Washer Replacement in the Great Lakes Region.* ACEEE.

DOE. (2010). *Commercial Washing Machine Standards.* Retrieved September 2014, from Regulations.gov: http://www1.eere.energy.gov/buildings/appliance_standards/product.aspx/productid/46

DOE. (2012a). *Clothes Washer Test Procedure*. Retrieved September 2014, from Appliance Standards: http://www.ecfr.gov/cgi-bin/text-idx?c=ecfr&SID=0b3799543b98dd9d20d3b6b531a04fb2&rgn=div5&view=text&node=10:3.0.1.4.18&idno=10#ap10.3.430_127.j2

DOE. (2012b). *Residential Clothes Washer Technical Support Document*. Retrieved September 2014, from Regulations.gov: http://www.regulations.gov/#!documentDetail;D=EERE-2008-BT-STD-0019-0047

DOE. (2012c). *Residential Clothes Washers Standards*. Retrieved September 2014, from Department of Energy: http://www1.eere.energy.gov/buildings/appliance_standards/product.aspx/productid/39

DOE. (2014). *Technical Support Document: Energy Efficiency Program for Consumer Products and Commercial and Industrial Equipment: Commercial Clothes Washers*.

ENERGY STAR. (2014a). *Clothes Washer Most Efficient.* Retrieved September 2014, from Products: https://www.energystar.gov/ia/partners/downloads/most_efficient/2015/Clothes_Washers_Proposed_ENERGY_STAR_Most_Efficient_2015_Recognition_Criteria.pdf?f0cc-4215

ENERGY STAR. (2014b). *ENERGY STAR Final Version 7.0 Clothes Washer Specification.* Retrieved September 2014, from Products: http://www.energystar.gov/sites/default/files/specs//ENERGY%20STAR%20Final%20Version%207.0%20Clothes%20Washer%20Program%20Requirements.pdf

MLA. (2014). *Why Community Area Laundry Rooms?* Retrieved from mla-online.com: http://www.mla-online.com/why.htm

PG&E. (2014). *Clothes Washers Calculations_proposed_CEE_2015_and_refrigerators_081214.xlsx.*

Sullivan, G., Parker, G., & Pugh, R. (2008). *Cal-UCONS Commercial Laundry Program Measurement and Evaluation Southern California Gas Company and San Diego Electric.* Richland, Washington: Battelle - Pacific Northwest Division.

Appendix D. Engineering Review of Residential Refrigerator/Freezer Compressor Efficiency Memo

D.1. Introduction

PG&E requested an assessment of the role that refrigerator/freezer compressor efficiency might play in a residential appliance energy efficiency program. PG&E raised the question of whether a promotion similar to "Intel inside" for personal computers might be effective with efficient compressors for residential refrigerators. If such a campaign were technically reasonable, and would be appealing to consumers, PG&E would consider approaching manufacturers with the concept.

As a starting point, the Research Into Action team conducted a limited investigation (work performed by SBW) of the energy savings that would follow improvements in compressor efficiency. The primary research question was, "What would be the impact on energy consumption of replacing the compressor in a standard efficiency refrigerator with a more efficient unit?" We restricted our investigation to of the following sources:

- The Department of Energy's (DOE's) Technical Support Document (TSD) in support of the federal standard on minimum refrigerator/freezer efficiency (DOE, 2011)
- Energy Star specifications and publications (EPA, 2014)
- Federal appliance standards (DOE, 2014)
- A small number of web searches. e.g. (General Electric, 2014), (Regional Technical Forum, 2013), searches for "refrigerator compressor efficiency," etc.

This memo presents the results of our preliminary research. We believe it is appropriate at this point to seek further guidance from PG&E as to how to proceed.

D.2. Conclusions

Our findings can be summarized in the following points.

- Manufacturers have most likely already integrated efficient compressors into most models meeting Energy Star specifications
- Further research would be necessary to determine current compressor efficiency levels, and the efficiency levels available above the levels incorporated into current models
- There may be significant energy savings and marketing potential in a campaign to increase the adoption of variable speed compressors

Further research questions include the following.

- What are current compressor energy efficiency ratio (EER) levels for different models at various tiers of energy consumption?
- What compressor EER levels are available from compressor manufacturers?
- What plans do manufacturers have with respect to integrating variable speed compressors into different models?
- What are the barriers to installing variable speed compressors into more models?

We were not able to directly answer the primary research question, for reasons we discuss in detail below. The primary reason we were unable to answer the research question is that we think that refrigerator manufacturers are most likely already integrating efficient compressors into their units to meet federal regulations that took effect September 15, 2014 and to meet ENERGY STAR efficiency levels. However, we could not find published compressor efficiency levels. The levels of compressor efficiency available as well as those currently in use are unanswered research questions. We think discussions with manufacturers to find the current levels of compressor efficiency would be a necessary next step in pursuing this concept.

One type of efficient compressor, a variable speed compressor (VSC), has the greatest reduction in energy consumption. At least one manufacturer, General Electric (GE), publishes the presence of this level of compressor in specifications for certain products (General Electric, 2014) (search for “variable speed compressor”). A marketing campaign directed towards this type of compressor may have the advantage that people can easily understand the savings associated with variable speed operation.

The alternative to a VSC, the standard constant speed compressor, has an Energy Efficiency Rating (EER), similar to an air conditioner. A campaign directed at constant speed compressors may need to build awareness of what constitutes an efficient EER for a given type of refrigerator.

Incorporation of a VSC into the manufacture of residential refrigerators is complex and may not be something manufacturers are willing to undertake for all models. Again, we recommend discussions with manufacturers.

D.3. Research Findings

To support federal appliance efficiency standards, DOE investigates options available to manufacturers to improve appliance efficiency. For residential refrigerators and freezers, the options identified by DOE include (DOE, 2011):

- Improved compressor efficiency
- Variable speed compressor (a variant of improved efficiency compressor)
- Increased levels of insulation
- Increased heat exchanger area

- Forced convection condenser
- Improved efficiency fan motors
- Adaptive defrost
- Vacuum insulation panels (VIPs)
- Variable anti-sweat heating

DOE has developed software to model refrigerator energy consumption. The modeling results showing the energy savings due to various components, combined with research into costs, determine a cost-effectiveness ranking. DOE starts with a standard efficiency appliance and then models the addition of enhancements, in order of cost-effectiveness, to determine which components would be necessary to achieve savings improvements over the baseline of 10%, 15%, 20%, etc.

The results, shown in

Reference Section 1, indicate that, based on the DOE modeling, improved efficiency compressors are one of the most cost-effective methods to reduce appliance energy consumption, and suggest further that variable speed compressors are a necessary component to achieve the greatest cost-effective reduction in energy consumption.

These tables do not show how the manufacturers have achieved the various tiers of energy savings. Manufacturers may have used other approaches to achieve savings. However, we think it is likely that efficient compressors are a key part of attaining Energy Star levels of efficiency.

Furthermore, with the recent tightening of federal standards, we would expect that formerly considered high-efficiency compressors (at the time of the 2011 Technical Support Document (TSD)) will be standard as of 2014 in many models, and that higher levels of compressor efficiency will be integral to achieving higher tiers of efficiency. These conclusions should be verified in discussions with manufacturers.

Reference Section 2 shows the increase in energy efficiency over the existing standards that will be required on September 15, 2014 (DOE, 2014). On average, the new standards require a 9% improvement in energy efficiency over current federal standards. The new ENERGY STAR specifications require a 10% improvement over the new federal standards (EPA, 2014). (ENERGY STAR specifications in effect prior to September 15, 2014 require a 20% improvement over federal standards (Regional Technical Forum, 2013), so at least initially, for many models, ENERGY STAR does not involve a significant tightening.)

Conducting a detailed assessment of the energy impact of a high-efficiency compressor would require significant time and effort. However, it is our judgment that this original research question into the energy impact of adding a high EER compressor to a standard appliance is not necessary because we think high EER compressors are already an essential component in attaining ENERGY STAR or higher levels of efficiency. The central question to us is a marketing question – Is there is value in developing a branding campaign based on "Efficient compressor inside" that would complement the ENERGY STAR brand? Such a campaign would likely need to identify a threshold EER as the minimum level necessary to qualify as "efficient" for each type of appliance, and identifying an appropriate threshold EER would require updated research into available compressor EERs. The relevant TSD was published in 2011, and much of the research in the document dates from 2009. So it may be that the relevant research is now out of date. However, we reviewed the catalog of a major manufacturer, Embraco, which shows higher levels of efficiency are only available in larger size refrigerators, which in turn, suggests that the TSD research may not be significantly out of date (Embraco, 2013).

For VSC's, on the other hand, the situation may be different. DOE modeling indicates that VSC's are only necessary to achieve the higher efficiency tiers. There is already some indication that a "variable speed" brand may be appealing as evidenced in GE's publication of this component in some of its specs, although we note that this component is described as a sound reduction feature. Given that the sound reduction non-energy benefit could be a driver for marketing VSC's, the Research Into Action team will conduct interviews with refrigerator manufacturers to ascertain whether there is interest in such branding, and , whether they would consider incorporating VSC's into a wider range of refrigerator models.

D.4. Works Cited

DOE. (2011). *Technical Support Document*. Retrieved August 28, 2014, from Department of Energy Residential Appliance Standards: http://www.regulations.gov/#!documentDetail;D=EERE-2008-BT-STD-0012-0128

DOE. (2014). *Appliance Standards*. Retrieved August 28, 2014, from DOE: http://www1.eere.energy.gov/buildings/appliance_standards/product.aspx/productid/43

Embraco. (2013). *Catalog*. Retrieved September 3, 2014, from Embraco product offerings: http://www.embraco.com/DesktopModules/DownloadsAdmin/Arquivos/NAR_Catalog_2013.pdf

EPA. (2014). *Appliance Specifications*. Retrieved August 28, 2014, from Energy Star: http://www.energystar.gov/products/certified-products/detail/7603/partners

General Electric. (2014). *Refrigerators*. Retrieved August 28, 2014, from General Electric: http://www.geappliances.com/appliances/refrigerators.htm

Regional Technical Forum. (2013). *Residential refrigerators*. Retrieved August 28, 2014, from Northwest Power & Conservation Council: http://rtf.nwcouncil.org/measures/res/ResRefrigerators_v3.1.xlsm

D.5. Reference Section 1

The following tables show the results of DOE refrigerator energy modeling (DOE, 2011). According to the modeling, efficient compressors are among the most cost-effective methods available to reduce energy consumption for almost all product classes. The EER levels shown reflect the better levels available at the time of the TSD. Variable speed compressors appear to be a necessary element in achieving the highest levels of energy savings.

Table 5-A.3.1: Incremental Cost Detail for 16 ft^3 Top-Mount Refrigerator-Freezer (Product Class 3)

Efficiency Level	Design Options Added	Design Option Costs						Incremental Costs	
		Material	Labor	Overhead	Depreciation	G&A, Profit	Total	Added	Cumulative
10%	Increase Condenser Size by 100%	$8.46	$0.00	$0.00	$0.00	$2.20	$10.66	$20.44	$20.44
	Increase Compressor EER from 5.55 to 6.1	$7.76	$0.00	$0.00	$0.00	$2.02	$9.78		
15%	Increase Compressor EER from 6.1 to 6.26	$3.00	$0.00	$0.00	$0.00	$0.78	$3.78	$9.20	$29.64
	Brushless DC Condenser Fan Motor	$4.30	$0.00	$0.00	$0.00	$1.12	$5.42		
20%	Increase Evaporator Size by 14%	$0.84	$0.00	$0.00	$0.00	$0.22	$1.06	$95.85	$125.50
	Adaptive Defrost	$8.00	$0.00	$0.00	$0.00	$2.08	$10.08		
	Variable Speed Compressor	$67.23	$0.00	$0.00	$0.00	$17.48	$84.71		
25%	12.2 sqft VIP in FZR Cabinet	$39.92	$4.17	$5.16		$12.80	$62.05	$62.05	$187.54
30%	2.9 sqft VIP in FZR Door	$9.50	$0.42	$1.16		$2.88	$13.96	$82.58	$270.12
	7.1 sqft VIP in FF Door	$23.08	$0.42	$2.75		$6.82	$33.07		
	6.7 sqft VIP in FF Cabinet	$22.00	$3.25	$2.96		$7.34	$35.55		
30.6%	1.9 sqft more VIP in FF Cabinet	$6.19	$0.91	$0.83		$2.06	$9.99	$9.99	$280.12

Table 5-A.3.2: Incremental Cost Detail for 21 ft^3 Top-Mount Refrigerator-Freezer (Product Class 3)

Efficiency Level	Design Options Added	Design Option Costs						Incremental Costs	
		Material	Labor	Overhead	Depreciation	G&A, Profit	Total	Added	Cumulative
10%	Increase Compressor EER from 4.92 to 5.57	$2.52	$0.00	$0.00	$0.00	$0.66	$3.18	$3.18	$3.18
15%	Increase Compressor EER from 5.57 to 5.96	$5.27	$0.00	$0.00	$0.00	$1.37	$6.63	$6.63	$9.81
20%	Increase Compressor EER from 5.94 to 6.08	$2.38	$0.00	$0.00	$0.00	$0.62	$3.00	$10.95	$20.76
	Increase Evaporator Size by 25%	$2.01	$0.00	$0.00	$0.00	$0.52	$2.53		
	Brushless DC Condenser Fan Motor	$4.30	$0.00	$0.00	$0.00	$1.12	$5.42		
25%	Brushless DC Evaporator Fan Motor	$4.10	$0.00	$0.00	$0.00	$1.07	$5.17	$5.17	$25.92
30%	Adaptive Defrost	$8.00	$0.00	$0.00	$0.00	$2.08	$10.08	$64.87	$90.80
	3.6 sqft VIP in FZR Door	$11.73	$0.42	$1.42		$3.53	$17.09		
	7.6 sqft VIP in FZR Cabinet	$24.82	$1.97	$3.13		$7.78	$37.70		
35.5%	Remove 0.9 sqft VIP FZR Cabinet	-$2.79	-$0.22	-$0.35		-$0.87	-$4.23	$81.24	$172.03
	Variable Speed Compressor	$67.84	$0.00	$0.00	$0.00	$17.64	$85.47		
40.5%	7.6 sqft VIP in FZR Cabinet	$18.73	$1.49	$2.37		$5.87	$28.45	$120.24	$292.27
	8.5 sqft VIP in FF Door	$27.76	$0.42	$3.30		$8.18	$39.65		
	10.9 sqft VIP in FF Cabinet	$35.56	$1.48	$4.33		$10.76	$52.13		

Table 5-A.3.3: Incremental Cost Detail for 21 ft^3 Built-in All-Refrigerator (Product Class 3A-BI)

Efficiency Level	Design Options Added	Design Option Costs						Incremental Costs	
		Material	Labor	Overhead	Depreciation	G&A, Profit	Total	Added	Cumulative
10%	Decrease Both Compressor Capacities (same EER)	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$7.14	$7.14
	10% Increase to Condenser Area	$1.00	$0.00	$0.00	$0.00	$0.40	$1.40		
	BLDC Evaporator Fan Upper Evaporator	$4.10	$0.00	$0.00	$0.00	$1.64	$5.74		
15%	BLDC Evaporator Fan Lower Evaporator	$4.10	$0.00	$0.00	$0.00	$1.64	$5.74	$11.76	$18.90
	BLDC Condenser Fan	$4.30	$0.00	$0.00	$0.00	$1.72	$ 6.02		
20%	VIP--Upper Door	$30.80	$0.42	$3.65		$13.95	$48.82	$108.20	$127.10
	VIP--Lower Cabinet	$35.49	$2.48	$4.44		$16.97	$59.38		
25%	VIP--Lower Cabinet	$24.20	$1.69	$3.03		$11.57	$40.48	$144.99	$272.09
	VIP--Upper Cabinet	$12.53	$4.17	$1.95		$7.46	$26.11		
	Upper System VSC	$56.00	$0.00	$0.00	$0.00	$22.40	$78.40		
29%	VIP--Lower Doors	$19.54	$0.42	$2.33		$8.92	$31.20	$109.60	$381.70
	Lower System VSC	$56.00	$0.00	$0.00	$0.00	$22.40	$78.40		

Table 5-A.3.4: Incremental Cost Detail for 18.5 ft^3 Bottom-Mount Refrigerator-Freezer (Product Class 5)

Efficiency Level	Design Options Added	Design Option Costs						Incremental Costs	
		Material	Labor	Overhead	Depreciation	G&A, Profit	Total	Added	Cumulative
10%	Increase Compressor EER from 5.61 to 6.26	$9.98	$0.00	$0.00	$0.00	$2.60	$12.58	$20.89	$20.89
	Brushless DC Evaporator Fan Motor	$4.10	$0.00	$0.00	$0.00	$1.07	$5.17		
	Increase Evaporator Size by 25%	$2.50	$0.00	$0.00	$0.00	$0.65	$3.15		
15%	Adaptive Defrost	$8.00	$0.00	$0.00	$0.00	$2.08	$10.08	$12.35	$33.24
	Brushless DC Condenser Fan Motor	$4.30	$0.00	$0.00	$0.00	$1.12	$5.42		
	Remove Evaporator Size Increase	-$2.50	$0.00	$0.00	$0.00	-$0.65	-$3.15		
20%	Variable Antisweat Heat Control	$17.48	$0.00	$0.00	$0.00	$4.54	$22.02	$25.17	$58.42
	Increase Evaporator Size by 25%	$2.50	$0.00	$0.00	$0.00	$0.65	$3.15		
25%	Variable Speed Compressor	$60.02	$0.00	$0.00	$0.00	$15.60	$75.62	$86.84	$145.26
	2.4 sqft VIP in FZR Door	$7.76	$0.21	$0.93		$2.31	$11.22		
30%	6.8 sqft VIP in FF Door	$22.09	$0.42	$2.63		$6.54	$31.68	$111.75	$257.01
	2.4 sqft more VIP in FZR Door	$7.76	$0.21	$0.93		$2.31	$11.22		
	13.7 sqft VIP in FZR Cabinet	$44.76	$4.17	$5.72		$14.21	$68.86		
32%	7.2 sqft VIP in FF Cabinet	$23.49	$4.17	$3.24		$8.03	$38.93	$38.93	$295.94

Table 5-A.3.5: Incremental Cost Detail for 25 ft^3 Bottom-Mount Refrigerator-Freezer (Product Class 5)

Efficiency Level	Design Options Added	Design Option Costs						Incremental Costs	
		Material	Labor	Overhead	Depreciation	G&A, Profit	Total	Added	Cumulative
10%	Increase Compressor EER from 5.00 to 5.67	$4.04	$0.00	$0.00	$0.00	$1.05	$5.08	$5.08	$5.08
15%	Increase Compressor EER from 5.67 to 5.97	$3.93	$0.00	$0.00	$0.00	$1.02	$4.95	$4.95	$10.03
20%	Increase Compressor EER from 5.97 to 6.26	$5.27	$0.00	$0.00	$0.00	$1.37	$6.64	$6.64	$16.67
25%	Brushless DC Evaporator Fan Motor	$4.10	$0.00	$0.00	$0.00	$1.07	$5.17	$17.11	$33.78
	Variable Anti-Sweat Heater Control	$9.48	$0.00	$0.00	$0.00	$2.46	$11.94		
30%	Brushless DC Condenser Fan Motor	$4.30	$0.00	$0.00	$0.00	$1.12	$5.42	$59.30	$93.09
	Variable Speed Compressor	$42.77	$0.00	$0.00	$0.00	$11.12	$53.89		
40.5%	9.2 sqft VIP in FF Door	$30.12	$0.42	$3.57		$8.87	$42.98	$197.92	$291.01
	5.9 sqft VIP in FZR Door	$19.34	$0.42	$2.31		$5.74	$27.81		
	14.8 sqft VIP in FZR Cabinet	$48.43	$4.17	$6.15		$15.28	$74.03		
	10.3sqft VIP in FF Cabinet	$33.57	$4.17	$4.41		$10.96	$53.10		

Table 5-A.3.6: Incremental Cost Detail for 21 ft^3 Built-In Bottom-Mount Refrigerator-Freezer (Product Class 5-BI)

<table>
<tr><th rowspan="2">Efficiency Level</th><th rowspan="2">Design Options Added</th><th colspan="6">Design Option Costs</th><th colspan="2">Incremental Costs</th></tr>
<tr><th>Material</th><th>Labor</th><th>Overhead</th><th>Depreciation</th><th>G&A, Profit</th><th>Total</th><th>Added</th><th>Cumulative</th></tr>
<tr><td rowspan="4">10%</td><td>Decrease FF Compressor Capacity (same EER)</td><td>$0.00</td><td>$0.00</td><td>$0.00</td><td>$0.00</td><td>$0.00</td><td>$0.00</td><td rowspan="4">$21.47</td><td rowspan="4">$21.47</td></tr>
<tr><td>10% Increase to Condenser Area</td><td>$1.00</td><td>$0.00</td><td>$0.00</td><td>$0.00</td><td>$0.40</td><td>$1.40</td></tr>
<tr><td>Increase Freezer Compressor EER to 6.26</td><td>$10.71</td><td>$0.00</td><td>$0.00</td><td>$0.00</td><td>$4.28</td><td>$14.99</td></tr>
<tr><td>1.0 sqft VIP--FZR Door</td><td>$3.18</td><td>$0.07</td><td colspan="2">$0.38</td><td>$1.45</td><td>$5.09</td></tr>
<tr><td rowspan="2">15%</td><td>Remove 1.0 sqft VIP--FZR Door</td><td>-$3.18</td><td>-$0.07</td><td colspan="2">-$0.38</td><td>-$1.45</td><td>-$5.09</td><td rowspan="2">$64.35</td><td rowspan="2">$85.82</td></tr>
<tr><td>FZR System VSC</td><td>$49.60</td><td>$0.00</td><td>$0.00</td><td>$0.00</td><td>$19.84</td><td>$69.43</td></tr>
<tr><td>20%</td><td>14.6 sqft VIP--FZR Compartment</td><td>$47.86</td><td>$3.34</td><td colspan="2">$5.99</td><td>$22.88</td><td>$80.07</td><td>$80.07</td><td>$165.89</td></tr>
<tr><td rowspan="3">25%</td><td>Add 3.6 sqft VIP -- FZR Compartment</td><td>$11.83</td><td>$0.83</td><td colspan="2">$1.48</td><td>$5.65</td><td>$19.79</td><td rowspan="3">$129.39</td><td rowspan="3">$295.28</td></tr>
<tr><td>6.0 sqft VIP--FZR Door</td><td>$19.54</td><td>$0.42</td><td colspan="2">$2.33</td><td>$8.92</td><td>$31.20</td></tr>
<tr><td>FF System VSC</td><td>$56.00</td><td>$0.00</td><td>$0.00</td><td>$0.00</td><td>$22.40</td><td>$78.40</td></tr>
<tr><td rowspan="2">27%</td><td>9.4 sqft VIP -- FF Door</td><td>$30.80</td><td>$0.42</td><td colspan="2">$3.65</td><td>$13.95</td><td>$48.82</td><td rowspan="2">$74.93</td><td rowspan="2">$370.22</td></tr>
<tr><td>3.8 sqft VIP -- FF Cabinet</td><td>$12.53</td><td>$4.17</td><td colspan="2">$1.95</td><td>$7.46</td><td>$26.11</td></tr>
</table>

Table 5-A.3.7: Incremental Cost Detail for 22 ft^{3}Side-Mount Refrigerator-Freezer with TTD Ice (Product Class 7)

Efficiency Level	Design Options Added	Design Option Costs						Incremental Costs	
		Material	Labor	Overhead	Depreciation	G&A, Profit	Total	Added	Cumulative
10%	Increase Compressor EER from 5.51 to 5.85	$4.45	$0.00	$0.00	$0.00	$1.16	$5.60	$12.54	$12.54
	Brushless DC Condenser Fan Motor	$4.30	$0.00	$0.00	$0.00	$1.12	$5.42		
	Increase Evaporator Area 19%	$1.21	$0.00	$0.00	$0.00	$0.31	$1.52		
15%	Increase Compressor EER from 5.85 to 6.22	$6.09	$0.00	$0.00	$0.00	$1.58	$7.68	$7.68	$20.22
20%	Increase Compressor EER from 6.22 to 6.26	$0.75	$0.00	$0.00	$0.00	$0.20	$0.95	$41.92	$62.14
	Increase Condenser Size by 27%	$3.91	$0.00	$0.00	$0.00	$1.02	$4.92		
	Variable Anti-Sweat Heater Control for Ice Dispenser	$9.48	$0.00	$0.00	$0.00	$2.46	$11.94		
	5.1 sqft VIP in FZR Door	$16.71	$0.42	$2.00		$4.98	$24.11		
25%	Remove 5.1 sqft VIP FZR Door	-$16.71	-$0.42	-$2.00		-$4.98	-$24.11	$47.49	$109.64
	Variable Speed Compressor	$44.71	$0.00	$0.00	$0.00	$11.62	$56.34		
	3.0 sqft VIP in FZR Cabinet	$9.66	$1.19	$1.27		$3.15	$15.27		
30%	7.4 sqft more VIP in FZR Cabinet	$24.15	$2.98	$3.17		$7.88	$38.17	$139.49	$249.13
	5.1 sqft VIP in FZR Door	$16.71	$0.42	$2.00		$4.98	$24.11		
	8 sqft VIP in FF Door	$26.28	$0.42	$3.12		$7.75	$37.57		
	7.8 sqft VIP in FF Cabinet	$25.60	$2.56	$3.30		$8.18	$39.64		
31%	4.9 sqft more VIP in FF Cabinet	$16.08	$1.61	$2.07		$5.14	$24.89	$24.89	$274.02

Table 5-A.3.8: Incremental Cost Detail for 26 ft^3 Side-Mount Refrigerator-Freezer with TTD Ice (Product Class 7)

Efficiency Level	Design Options Added	Design Option Costs						Incremental Costs	
		Material	Labor	Overhead	Depreciation	G&A, Profit	Total	Added	Cumulative
10%	Increase Compressor EER from 5.21 to 5.86	$5.76	$0.00	$0.00	$0.00	$1.50	$7.26	$7.26	$7.26
15%	Brushless DC Evaporator Fan Motor	$4.10	$0.00	$0.00	$0.00	$1.07	$5.17	$10.58	$17.84
	Brushless DC Condenser Fan Motor	$4.30	$0.00	$0.00	$0.00	$1.12	$5.42		
20%	Increase Compressor EER from 5.86 to 6.11	$3.90	$0.00	$0.00	$0.00	$1.01	$4.91	$4.91	$22.75
25%	Increase Compressor EER from 6.11 to 6.26	$2.82	$0.00	$0.00	$0.00	$0.73	$3.55	$56.03	$78.78
	Variable Anti-Sweat Heater Control for Ice Dispenser	$17.48	$0.00	$0.00	$0.00	$4.54	$22.02		
	Increase Condenser Size by 10%	$1.21	$0.00	$0.00	$0.00	$0.31	$1.53		
	6.2 sqft VIP in FZR Door	$20.14	$0.42	$2.41		$5.97	$28.93		
30%	Variable Speed Compressor	$57.55	$0.00	$0.00	$0.00	$14.96	$72.51	$85.79	$164.57
	2.6 sqft VIP in FZR Cabinet	$8.51	$0.93	$1.10		$2.74	$13.29		
35%	9.1 sqft more VIP in FZR Cabinet	$29.71	$3.24	$3.86		$9.57	$46.38	$151.83	$316.41
	8.2 sqft VIP in FF Door	$26.65	$0.42	$3.17		$7.86	$38.09		
	13.4 sqft VIP in FF Cabinet	$43.70	$4.17	$5.60		$13.90	$67.36		

Table 5-A.3.9: Incremental Cost Detail for 28 ft^3 Built-In Side-Mount Refrigerator-Freezer with TTD ice service (Product Class 7-BI)

Efficiency Level	Design Options Added	Design Option Costs						Incremental Costs	
		Material	Labor	Overhead	Depreciation	G&A, Profit	Total	Added	Cumulative
10%	High Efficiency Compressor	$7.31	$0.00	$0.00	$0.00	$2.92	$10.23	$51.45	$51.45
	Heat Exchanger Improvement	$2.00	$0.00	$0.00	$0.00	$0.80	$2.80		
	Variable Anti-sweat	$9.50	$0.00	$0.00	$0.00	$3.80	$13.30		
	Partial VIP to Freezer Door	$15.81	$0.25	$1.88		$7.18	$25.12		
15%	Eliminate VIP to Freezer Door	-$15.81	-$0.25	-$1.88		-$7.18	-$25.12	$72.02	$123.47
	Variable Speed Compressor	$69.38	$0.00	$0.00	$0.00	$27.75	$97.14		
20%	VIP to Freezer Door	$26.36	$0.42	$3.13		$11.96	$41.86	$158.06	$281.53
	VIP to Freezer Cabinet	$70.14	$4.17	$8.69		$33.20	$116.20		
22%	VIP to Fresh Food Cabinet	$11.59	$4.17	$1.84		$7.04	$24.64	$89.74	$371.27
	VIP to Fresh Food Door	$41.22	$0.42	$4.87		$18.60	$65.10		

Table 5-A.3.10: Incremental Cost Detail for 14 ft^3 Upright Freezer with Auto Defrost (Product Class 9)

Efficiency Level	Design Options Added	Design Option Costs						Incremental Costs	
		Material	Labor	Overhead	Depreciation	G&A, Profit	Total	Added	Cumulative
10%	Brushless DC Evaporator Fan Motor	$4.10	$0.00	$0.00	$0.00	$1.07	$5.17	$10.40	$10.40
	Increase compressor efficiency from 5.04 to 5.69	$4.15	$0.00	$0.00	$0.00	$1.08	$5.23		
15%	Increase compressor efficiency from 5.69 to 6.08	$9.03	$0.00	$0.00	$0.00	$2.35	$11.38	$21.14	$31.54
	Door Insulation Thickness Increase of 0.21 inches	$0.75	$0.00	$0.00	$7.00	$2.02	$9.77		
20%	Door Insulation Thickness Increase of 0.79 inches	$2.83	$0.00	$0.00	$0.00	$0.74	$3.56	$13.64	$45.18
	Adaptive Defrost	$8.00	$0.00	$0.00	$0.00	$2.08	$10.08		
25%	Add 0.22" Insulation to Walls	$2.59	$0.00	$0.00	$23.00	$6.65	$32.24	$32.24	$77.43
30%	Add 0.34" more Insulation to Walls	$3.92	$0.00	$0.00	$0.00	$1.02	$4.94	$4.94	$82.37
35%	Remove 0.06" Wall Insulation	-$0.68	$0.00	$0.00	$0.00	-$0.18	-$0.86	$85.18	$167.56
	Variable Speed Compressor	$68.29	$0.00	$0.00	$0.00	$17.76	$86.05		
40%	Add 0.5" Wall Insulation	$5.76	$0.00	$0.00	$0.00	$1.50	$7.26	$34.16	$201.71
	5.7 sqft VIP in Door	$18.46	$0.23	$2.65		$5.55	$26.90		
43%	4.6 sqft more VIP in Door	$14.94	$0.19	$2.15		$4.49	$21.76	$113.38	$315.09
	18.9 sqft VIP in Cabinet	$61.59	$2.08	$9.04		$18.90	$91.61		

Table 5-A.3.11: Incremental Cost Detail for 20 ft^3 Upright Freezer with Auto Defrost (Product Class 9)

Efficiency Level	Design Options Added	Design Option Costs						Incremental Costs	
		Material	Labor	Overhead	Depreciation	G&A, Profit	Total	Added	Cumulative
10%	Brushless DC Evaporator Fan Motor	$4.10	$0.00	$0.00	$0.00	$1.07	$5.17	$11.98	$11.98
	Increase Compressor EER from 5.73 to 6.1	$5.41	$0.00	$0.00	$0.00	$1.41	$6.82		
15%	Increase Compressor EER from 6.1 to 6.24	$2.63	$0.00	$0.00	$0.00	$0.68	$3.31	$13.39	$25.37
	Adaptive Defrost	$8.00	$0.00	$0.00	$0.00	$2.08	$10.08		
20%	Increase Evaporator Size by 22%	$1.47	$0.00	$0.00	$0.00	$0.38	$1.86	$16.98	$42.35
	Forced Convection Condenser with Brushless DC Condenser Fan	$12.00	$0.00	$0.00	$0.00	$3.12	$15.12		
25%	Add 0.9 inch Insulation to Door	$4.28	$0.00	$0.00	$7.00	$2.93	$14.22	$14.22	$56.57
30%	Remove 0.2 inch Insulation from Door	-$0.95	$0.00	$0.00	$0.00	-$0.25	-$1.20	$37.50	$94.06
	Add 0.5 inch Insulation to Cabinet	$7.71	$0.00	$0.00	$23.00	$7.98	$38.69		
35%	Add 0.5 inch Insulation to Cabinet	$7.76	$0.00	$0.00	$0.00	$2.02	$9.78	$9.78	$103.84
40%	Variable Speed Compressor	$78.00	$0.00	$0.00	$0.00	$20.28	$98.28	$98.28	$202.12
44.0%	14.4 sqft VIP in Door	$46.97	$0.42	$6.73		$14.07	$68.18	$180.00	$382.12
	23.1 sqft VIP in Cabinet	$75.63	$2.08	$11.03		$23.07	$111.82		

Table 5-A.3.12: Incremental Cost Detail for 22 ft^3 Built-In Upright Freezer (Product Class 9-BI)

Efficiency Level	Design Options Added	Design Option Costs						Incremental Costs	
		Material	Labor	Overhead	Depreciation	G&A, Profit	Total	Added	Cumulative
10%	Increase Compressor EER to 6.29	$11.20	$0.00	$0.00	$0.00	$4.48	$15.68	$15.68	$15.68
15%	BLDC Fan for Evaporator	$4.10	$0.00	$0.00	$0.00	$1.64	$5.74	$11.76	$27.44
	BLDC Fan for Condenser	$4.30	$0.00	$0.00	$0.00	$1.72	$6.02		
20%	10% Increase to Condenser Area	$1.00	$0.00	$0.00	$0.00	$0.40	$1.40	$71.80	$99.23
	Variable Speed Compressor	$44.80	$0.00	$0.00	$0.00	$17.92	$62.72		
	1.5 sqft VIP Upper Door	$4.84	$0.07	$0.57		$2.19	$7.67		
25%	VIP Upper Door (Full Coverage)	$25.96	$0.35	$3.08		$11.76	$41.15	$112.50	$211.74
	13.1 sqft VIP Lower Cabinet	$42.65	$2.98	$5.34		$20.39	$71.36		
27%	VIP Lower Cabinet (Full Coverage)	$17.04	$1.19	$2.13		$8.14	$28.50	$85.82	$297.56
	VIP--Lower Door	$19.54	$0.42	$2.33		$8.92	$31.20		
	VIP--Upper Cabinet	$12.53	$4.17	$1.95		$7.46	$26.11		

Table 5-A.3.13: Incremental Cost Detail for 15 ft^3 Chest Freezer (Product Class 10)

Efficiency Level	Design Options Added	Design Option Costs						Incremental Costs	
		Material	Labor	Overhead	Depreciation	G&A, Profit	Total	Added	Cumulative
10%	Increase Compressor EER from 4.92 to 5.48	$1.74	$0.00	$0.00	$0.00	$0.45	$2.19	$2.19	$2.19
15%	Increase Compressor EER from 5.48 to 5.81	$4.39	$0.00	$0.00	$0.00	$1.14	$5.53	$5.53	$7.72
20%	Increase Compressor EER from 5.81 to 6.08	$3.99	$0.00	$0.00	$0.00	$1.04	$5.02	$14.66	$22.39
	Add 0.24 inch Insulation to Door	$0.65	$0.00	$0.00	$7.00	$1.99	$9.64		
25%	Add 0.76 inch Insulation to Door	$2.11	$0.00	$0.00	$0.00	$0.55	$2.66	$37.50	$59.89
	Add 0.15 inch Insulation to Cabinet	$1.66	$0.00	$0.00	$26.00	$7.19	$34.85		
30%	Add 0.35 inch Insulation to Cabinet	$3.78	$0.00	$0.00	$0.00	$0.98	$4.77	$4.77	$64.66
35%	Variable Speed Compressor	$46.15	$0.00	$0.00	$0.00	$12.00	$58.14	$58.14	$122.80
44%	Add 0.25 inch Insulation to Cabinet	$2.65	$0.00	$0.00	$0.00	$0.69	$3.33	$85.87	$208.67
	8.2 sqft VIP on bottom	$26.66	$1.39	$3.98		$8.33	$40.36		
	8.8 sqft VIP on door	$28.89	$0.42	$4.16		$8.70	$42.17		

Table 5-A.3.14: Incremental Cost Detail for 20 ft^3 Chest Freezer (Product Class 10)

Efficiency Level	Design Options Added	Design Option Costs						Incremental Costs	
		Material	Labor	Overhead	Depreciation	G&A, Profit	Total	Added	Cumulative
10%	Increase Condenser Size by 24%	$1.68	$0.00	$0.00	$0.00	$0.44	$2.12	$10.68	$10.68
	Increase Compressor EER from 5.71 to 6.16	$6.80	$0.00	$0.00	$0.00	$1.77	$8.56		
15%	Increase Compressor EER from 6.16 to 6.25	$1.69	$0.00	$0.00	$0.00	$0.44	$2.13	$10.95	$21.63
	Convert Door Insulation to PU Foam	$0.00	$0.00	$0.00	$7.00	$1.82	$8.82		
20%	Add 1 inch Insulation to Door	$3.47	$0.00	$0.00	$0.00	$0.90	$4.37	$4.37	$26.00
25%	Add 0.35 inch Insulation to Cabinet	$4.77	$0.00	$0.00	$26.00	$8.00	$38.78	$38.78	$64.78
30%	Add 0.4 inch Insulation to Cabinet	$5.32	$0.00	$0.00	$0.00	$1.38	$6.70	$28.91	$93.69
	4.5 sqft VIP in Bottom Wall	$14.82	$0.62	$2.19		$4.58	$22.21		
35%	Remove 4.5 sqft VIP Bottom Wall	-$14.82	-$0.62	-$2.19		-$4.58	-$22.21	$37.65	$131.34
	Variable Speed Compressor	$47.51	$0.00	$0.00	$0.00	$12.35	$59.87		
39%	10.2 sqft VIP in Bottom Wall	$33.46	$1.39	$4.95		$10.35	$50.14	$107.09	$238.43
	12 sqft VIP in Door	$39.16	$0.42	$5.62		$11.75	$56.95		

Table 5-A.3.15: Incremental Cost Detail for 1.7 ft[3] Compact Refrigerator (Product Class 11)

Efficiency Level	Design Options Added	Design Option Costs						Incremental Costs	
		Material	Labor	Overhead	Depreciation	G&A, Profit	Total	Added	Cumulative
10%	Increase Evaporator Size by 20%	$0.27	$0.00	$0.00	$0.00	$0.07	$0.34	$2.61	$2.61
	Increase Compressor EER from 3.02 to 3.20	$1.80	$0.00	$0.00	$0.00	$0.47	$2.27		
15%	Increase Compressor EER from 3.20 to 3.47	$2.70	$0.00	$0.00	$0.00	$0.70	$3.40	$3.40	$6.01
20%	Increase Condenser Size by 19%	$0.39	$0.00	$0.00	$0.00	$0.10	$0.49	$5.12	$11.13
	Add 3/4 inch Insulation in Door	$0.67	$0.00	$0.00	$3.00	$0.95	$4.62		
25%	Add 0.18 inch Insulation in Cabinet	$0.60	$0.00	$0.00	$10.00	$2.76	$13.36	$13.36	$24.49
30%	Add 0.57 inch Insulation in Cabinet	$2.00	$0.00	$0.00	$0.00	$0.52	$2.51	$2.51	$27.00
35%	Eliminate all previous Design Options	-$8.43	$0.00	$0.00	-$13.00	-$5.57	-$27.00	$43.56	$70.56
	Variable Speed Compressor	$56.00	$0.00	$0.00	$0.00	$14.56	$70.56		
40%	Convert to Isobutane Refrigerant	$8.00	$0.00	$0.00	$1.00	$2.34	$11.34	$11.34	$81.90
45%	Increase Evaporator Size by 20%	$0.27	$0.00	$0.00	$0.00	$0.07	$0.34	$5.46	$87.36
	Increase Condenser Size by 19%	$0.39	$0.00	$0.00	$0.00	$0.10	$0.49		
	Add 3/4 inch Insulation in Door	$0.67	$0.00	$0.00	$3.00	$0.95	$4.62		
50%	Add 3/4 inch Insulation in Cabinet	$2.60	$0.00	$0.00	$10.00	$3.28	$15.88	$15.88	$103.23
55%	Add 4.7 sqft VIP in Cabinet	$15.38	$4.17	$3.83		$6.08	$29.45	$41.06	$144.29
	Add 2.2 sqft VIP in Door	$7.29	$0.42	$1.51		$2.39	$11.61		

Table 5-A.3.16: Incremental Cost Detail for 4.0 ft^3 Compact Refrigerator (Product Class 11)

Efficiency Level	Design Options Added	Design Option Costs						Incremental Costs	
		Material	Labor	Overhead	Depreciation	G&A, Profit	Total	Added	Cumulative
10%	Increase Compressor EER from 4.57 to 5.1	$5.30	$0.00	$0.00	$0.00	$1.38	$6.68	$6.68	$6.68
15%	Increase Compressor EER from 5.1 to 5.3	$2.30	$0.00	$0.00	$0.00	$0.60	$2.90	$3.65	$10.32
	Increase Condenser Size by 22%	$0.59	$0.00	$0.00	$0.00	$0.15	$0.75		
20%	Add 3/4 inch Insulation to Door	$0.92	$0.00	$0.00	$3.00	$1.02	$4.94	$4.94	$15.26
25%	Convert to Isobutane Refrigerant	$4.00	$0.00	$0.00	$1.00	$1.30	$6.30	$6.69	$21.95
	Add 1/4 inch Insulation to Door	$0.31	$0.00	$0.00	$0.00	$0.08	$0.39	$14.23	
30%	Add 0.22 inch Insulation to Cabinet	$0.98	$0.00	$0.00	$10.00	$2.86	$13.84	$13.45	$35.40
	Remove 1/4 inch Insulation from Door	-$0.31	$0.00	$0.00	$0.00	-$0.08	-$0.39		
35%	Add 0.22 inch Insulation to Cabinet	$0.99	$0.00	$0.00	$0.00	$0.26	$1.25	$1.25	$36.66
40%	Add 0.31 inch Insulation to Cabinet	$1.37	$0.00	$0.00	$0.00	$0.36	$1.73	$1.73	$38.38
45%	Variable Speed Compressor	$52.40	$0.00	$0.00	$0.00	$13.62	$66.02	$49.20	$87.59
	Remove 3/4 inch Cabinet Insulation	-$3.35	$0.00	$0.00	-$10.00	-$3.47	- $16.82		
50%	Add 0.23 inch Insulation to Cabinet	$1.02	$0.00	$0.00	$10.00	$2.87	$13.89	$13.89	$101.47
62%	Add 0.32 inch Insulation to Cabinet	$2.33	$0.00	$0.00	$0.00	$0.61	$2.93	$66.16	$167.63
	7.2 sqft VIP Cabinet	$23.57	$4.17	$5.44		$8.62	$41.79		
	4.2 sqft VIP Door	$13.81	$0.42	$2.79		$4.42	$21.43		

Table 5-A.3.17: Incremental Cost Detail for 3.4 ft^3 Compact Chest Freezer (Product Class 18)

Efficiency Level	Design Options Added	Design Option Costs						Incremental Costs	
		Material	Labor	Overhead	Depreciation	G&A, Profit	Total	Added	Cumulative
10%	Increase Compressor EER from 3.74 to 4.17	$4.30	$0.00	$0.00	$0.00	$1.12	$5.42	$5.42	$5.42
15%	Increase Compressor EER from 4.17 to 4.29	$1.20	$0.00	$0.00	$0.00	$0.31	$1.51	$10.45	$15.87
	Add 1 inch Insulation to Door	$1.09	$0.00	$0.00	$6.00	$1.84	$8.94		
20%	Remove 1/4 inch Insulation from Door	-$0.27	$0.00	$0.00	$0.00	-$0.07	-$0.34	$35.22	$51.09
	Add 0.48 inch Insulation to Cabinet	$2.23	$0.00	$0.00	$26.00	$7.34	$35.57		
25%	Add 0.27 inch Insulation to Cabinet	$1.22	$0.00	$0.00	$0.00	$0.32	$1.54	$13.96	$65.05
	Add 2.1 sqft VIP in Bottom Wall	$6.85	$1.39	$1.62		$2.56	$12.42		
30%	Remove all design options through 25% Level	-$16.62	-$1.39	-$33.62		-$13.42	-$65.05	$5.51	$70.56
	Variable Speed Compressor	$56.00	$0.00	$0.00	$0.00	$14.56	$70.56		
35%	Add 0.75 inch Insulation to Door	$0.82	$0.00	$0.00	$6.00	$1.77	$8.59	$8.59	$79.15
43.3%	Add 0.75 inch Insulation to Cabinet	$3.45	$0.00	$0.00	$26.00	$7.66	$37.11	$66.56	$145.71
	Add 2.1 sqft VIP in Bottom Wall	$6.85	$1.39	$1.62		$2.56	$12.42		
	Add 3.3 sqft VIP in Door	$10.89	$0.42	$2.22		$3.51	$17.03		

Table 5-A.3.18: Incremental Cost Detail for 7.0 ft^3 Compact Chest Freezer (Product Class 18)

Efficiency Level	Design Options Added	Design Option Costs						Incremental Costs	
		Material	Labor	Overhead	Depreciation	G&A, Profit	Total	Added	Cumulative
10%	Increase Compressor EER from 4.50 to 5.02	$5.20	$0.00	$0.00	$0.00	$1.35	$6.55	$6.55	$6.55
15%	Increase Compressor EER from 5.02 to 5.27	$2.50	$0.00	$0.00	$0.00	$0.65	$3.15	$10.98	$17.53
	Add 0.12 inch Insulation to Door	$0.22	$0.00	$0.00	$6.00	$1.62	$7.83		
20%	Add 0.63 inch Insulation to Door	$1.14	$0.00	$0.00	$0.00	$0.30	$1.44	$36.84	$54.37
	Add 0.26 inch Insulation to Cabinet	$2.09	$0.00	$0.00	$26.00	$7.30	$35.39		
25%	Add 0.36 inch Insulation to Cabinet	$2.91	$0.00	$0.00	$0.00	$0.76	$3.66	$3.66	$58.03
30%	Remove all design options through 25% Level	-$14.06	$0.00	$0.00	-$32.00	-$11.97	-$58.03	$47.08	$105.11
	Variable Speed Compressor	$56.00	$0.00	$0.00	$0.00	$14.56	$70.56		
	Add 0.18 inch Insulation to Cabinet	$1.42	$0.00	$0.00	$26.00	$7.13	$34.55		
35%	Add 0.47 inch Insulation to Cabinet	$3.71	$0.00	$0.00	$0.00	$0.96	$4.67	$4.67	$109.79
40%	Add 0.11 inch Insulation to Cabinet	$0.85	$0.00	$0.00	$0.00	$0.22	$1.07	$58.69	$168.47
	Add 3/4 inch Insulation to Door	$1.36	$0.00	$0.00	$6.00	$1.91	$9.27		
	Add 4.1 sqft VIP to Cabinet Bottom	$13.50	$1.39	$2.92		$4.63	$22.43		
	Add 5.1 sqft VIP to Door	$16.78	$0.42	$3.37		$5.35	$25.91		

D.6. Reference Section 2

This table compares maximum annual consumption for a select set of residential refrigerators set to take effect September 15, 2014 with current standards. The average increase in performance for these models due to the new standards is 9%.

Federal Class No.	Configuration	Defrost Type	Through the Door Ice	Volume Group	NAECA as of July 1, 2001 Maximum Energy Usage in kWh/year	2008 Maximum annual consumption, kWh	Federal Regulations as of Sept 15, 2014	2014 Maximum annual consumption, kWh	Percent better, 2014 over 2008
1	Internal	Manual	Non_TTD_Ice	Standard	8.82*AV+248.4	465	7.99AV + 225.0	421	9%
1	No_freezer	Manual	Non_TTD_Ice	Standard	8.82*AV+248.4	465	6.79AV + 193.6	360	23%
2	Top	Partial	Non_TTD_Ice	Standard	8.82*AV+248.4	465	7.99AV + 225.0	421	9%
3	Top	Auto	Non_TTD_Ice	Standard	9.80*AV+276	517	8.07AV + 233.7	432	16%
4	Side	Auto	Non_TTD_Ice	Standard	4.91*AV+507.5	628	8.51AV + 297.8	507	19%
5	Bottom	Auto	Non_TTD_Ice	Standard	4.60*AV+459	572	8.85AV + 317.0	534	7%
5	Internal	Auto	Non_TTD_Ice	Standard	4.60*AV+459	572	8.85AV + 401.0	618	-8%
6	Top	Auto	TTD_Ice	Standard	10.20*AV+356	607	8.40AV + 385.4	592	2%
7	Side	Auto	TTD_Ice	Standard	10.10*AV+406	654	8.54AV + 432.8	643	2%
11	Top	Manual	Non_TTD_Ice	Compact	10.70*AV+299	362	9.03AV + 252.3	306	16%
11	No_freezer	Manual	Non_TTD_Ice	Compact	10.70*AV+299	362	7.84AV + 219.1	265	27%
12	Top	Partial	Non_TTD_Ice	Compact	7.00*AV+398	439	5.91AV + 335.8	371	16%
13	Top	Auto	Non_TTD_Ice	Compact	12.70*AV+355	430	6.82AV + 456.9	497	-16%
15	Bottom	Auto	Non_TTD_Ice	Compact	13.10*AV+367	444	11.80AV + 339.2	409	8%
13	Top	Auto	TTD_Ice	Compact	12.70*AV+355	430	11.80AV + 339.2	409	5%
Average									9%