AHAM
ASSOCIATION OF HOME APPLIANCE MANUFACTURERS

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April 8, 2011

Via E-Mail

Amanda Stevens
U.S. Environmental Protection Agency
ENERGY STAR Appliance Program
appliances@energystar.gov

Re: ENERGY STAR Program Requirements Product Specification
For Residential Dishwashers, Eligibility Criteria, Final Draft, Version 5.0

Dear Ms. Stevens:

On behalf of the Association of Home Appliance Manufacturers (AHAM), I would like to provide our comments on the ENERGY STAR Program Requirements Product Specification for Residential Dishwashers, Eligibility Criteria, Final Draft, Version 5.0.

The Association of Home Appliance Manufacturers (AHAM) represents manufacturers of major, portable and floor care home appliances, and suppliers to the industry. AHAM's membership includes over 150 companies throughout the world. In the U.S., AHAM members employ tens of thousands of people and produce more than 95% of the household appliances shipped for sale. The factory shipment value of these products is more than $30 billion annually. The home appliance industry, through its products and innovation, is essential to U.S. consumer lifestyle, health, safety and convenience. Through its technology, employees and productivity, the industry contributes significantly to U.S. jobs and economic security. Home appliances also are a success story in terms of energy efficiency and environmental protection. New appliances often represent the most effective choice a consumer can make to reduce home energy use and costs.

AHAM supports EPA and the Department of Energy (DOE) in their efforts to provide incentives to manufacturers, retailers, and consumers for continual energy efficiency improvement, as long as product performance can be maintained for the consumer. AHAM continues to believe that ENERGY STAR's previously scheduled, and long planned for, increases in eligibility criteria levels for residential dishwashers should not be changed just a matter of months before they were scheduled to go into effect. In addition, we support the addition of a performance metric with the proposed Version 5.0 Tier 2 qualification criteria, but it needs to be done right for it to provide the level of confidence that the consumer expects to have in the ENERGY STAR brand and to provide certainty to ENERGY STAR partners. To do it right will take time, and the Tier 2 effective date should take that into account.

## I. Qualification Criteria

### A. The Energy and Water Consumption Levels Should Not Be Increased at This Time.

As we have previously commented, (twice and together with energy efficiency advocates), AHAM strongly believes that the energy and water consumption requirement levels previously set for July 2011 should be retained. Manufacturers have been planning and investing resources in designs that would be consistent with the agreement that meet the ENERGY STAR levels currently set to increase in July, 2011. If ENERGY STAR changes the specification at this late date, it will result in market disruption and the potential for stranded investments. Manufacturers took the previous Tier 2 proposal seriously. To change things now risks stranding some of their investments and also could make manufacturers less willing to invest in Tier 2 products in the future, undermining the rapid progress that Tier 2 standards are designed to foster. Also, by delaying the start of a new ENERGY STAR tier by six months, significant energy savings will be lost that will take more than six months to make up with the proposed version 5.0 specification.

AHAM, energy efficiency advocates, and consumer groups recently held successful negotiations which resulted in a major agreement on federal minimum energy conservations for five products, and related test procedures, ENERGY STAR, and financial incentive provisions. The description of this package can be found at Attachment A to our comments dated November 10, 2010. The agreement consists of recommendations for updates and extensions of the manufacturer tax credit for the production of super-efficient appliances. These incentives encourage manufacturers to develop, commercialize, and sell very high efficiency products, helping to transform markets faster than with standards alone. The lower tiers of the current federal incentives are phased-out under the new agreement and new, higher tiers are added. Lawrence Berkeley National Laboratory has estimated the tax credits for residential dishwashers would save an additional 0.07 quads of primary energy and 0.03 billion gallons of water over 30 years, for a total energy savings of 0.84 quads and a total water savings of 0.47 trillion gallons.

The agreement does not include ENERGY STAR levels, but it does include aspects that relate to ENERGY STAR including the July 1, 2011, specification and the proposed new EPA specification

The ENERGY STAR levels that are now scheduled to take effect on July 1, 2011, are the basis for new minimum efficiency standards that the agreement recommends take effect January 1, 2013. In developing this recommendation for new standards, the parties to the agreement recognized the value of using the ENERGY STAR specification to help with the transition to the new standard. EPA's proposal to drop the July 1, 2011, specification and further increase the eligibility criteria will make the transition to the 2013 energy efficiency standard much more difficult. Thus, it is not something AHAM can support.

Furthermore, the ENERGY STAR levels EPA proposes for January 3, 2012, (final draft, Version 5.0) are the same as the second tier of agreed to tax credit levels which are proposed to apply to dishwashers manufactured in 2011, 2012, and 2013. Those levels, and the associated timeframes for tax credits, were agreed to by all parties (manufacturers, energy efficiency advocates, and consumer groups) with an understanding that it will take time for manufacturers to develop and widely market equipment at this new level, and that initially such levels are only suitable for a portion of shipments. We are concerned that EPA's proposal to have a new level effective January 3, 2012, would not provide enough time for manufacturers to bring new products to market. Furthermore, based on AHAM's latest data, the number of products currently meeting the new proposed level is less than ENERGY STAR's goal of achieving approximately 25% of the market. Instead, ENERGY STAR should maintain the previously set increase for July 1, 2011. Failure to do so undercuts both a broadly supported appliance standards agreement and the credibility and stability of the ENERGY STAR program itself.

B. The Proposed Effective Date for Version 5.0 Tier 2 Is Too Soon.

The final draft proposes to retain a Tier 2 level to be effective July 1, 2013, and levels to be determined. We question whether any two tiered specification will be honored by ENERGY STAR based on the proposed changes to the Tier 2 level that was scheduled to go into effect in less than four months. That being said, AHAM appreciates that EPA pushed the effective date for proposed Version 5.0, Tier 2 back from its previously proposed date of January 1, 2013, after AHAM commented that that effective date would not allow enough time to properly consider the revised AHAM DW-1 performance test procedure. But July 1, 2013, is still too soon for a Tier 2 level that includes performance to be effective.

We reiterate that AHAM supports the addition of a performance metric, especially as eligibility criteria continue to increase. Accordingly, we agree that, should EPA find it necessary to include a Tier 2 level in Version 5.0, it should be "to be determined" because the energy and water criteria will need to be tied to the performance test procedure and level requirement, which will later be determined. But, as we have previously stated, the addition of performance needs to be done right for it to provide the level of confidence that the consumer expects to have in the ENERGY STAR brand and to provide certainty to ENERGY STAR partners.

A July 1, 2013, effective date will not provide DOE (per the EPA-DOE Memorandum of Understanding and the just-released 2011 DOE-EPA Work Plan) enough time to review the revised AHAM DW-1 and determine appropriate eligibility criteria and performance levels. Even if the AHAM DW-1 revisions were to be complete on January 1, 2013, that leaves only six months before the Tier 2 level and performance requirement would become effective—that is shorter than the minimum nine month lead time required by law for effective dates of revised ENERGY STAR specifications, and is not enough time for manufacturers to plan products to meet the specification. We would not expect that EPA (or DOE) would want to adopt an incomplete test procedure in its specification, which is what would be required for the proposed July 1, 2013, effective date, even were AHAM's revisions to be complete on January 1, 2013. EPA (or, preferably, DOE) should review the revised test procedure upon its completion to determine if it is indeed appropriate for inclusion in the ENERGY STAR specification. Furthermore, to better set a pass/fail level for performance, as EPA is proposing to do, it will need to collect data on the results produced by the revised test procedure.

Accordingly, we urge EPA to push the effective date for Version 5.0 Tier 2 to account for *at the very least* the nine month lead time, which is required by law. We note as well that the effective date for Tier 2 should not be used as a means to force the completion of AHAM DW-1 revisions, which, as we have explained in previous comments, will require a substantial amount of time to be completed in a way that yields accurate, repeatable, reproducible, and enforceable results. AHAM has committed to finishing revisions in 2013, but cannot guarantee a January 1, 2013, completion date.

We also continue to reiterate that DOE, which has considerable knowledge and experience with test procedures, is the proper agency to decide whether and how to incorporate performance into the test procedure for residential dishwashers, and EPA should not circumvent DOE's expertise by deciding what test procedure should measure performance. These views are consistent with the EPA-DOE Work Plan issued in April 2011. When evaluating performance for the Version 5.0 Tier 2, EPA should rely on DOE's expertise, and avoid redundant development of expertise in the federal government that would be a wasteful use of resources.

## II. Definitions

AHAM appreciates that EPA in this final draft has harmonized its definitions with DOE's where there is a DOE definition. With regard to the updated definition of "basic model," we encourage EPA to verify with DOE that that definition, which is currently stated in 76 Fed. Reg. 12422, 12429, will actually be included in the regulatory text. It may be best for the ENERGY STAR specification to cite the specific section in the regulatory text, and to clarify with DOE whether there are any product specific changes relative to dishwashers.

## III. Smart Requirements

EPA stated that it intends to evaluate the addition of ENERGY STAR requirements to addressed "intelligent product capabilities and smart grid functionality." AHAM continues to believe that it is possible to recognize smart capabilities in ENERGY STAR requirements now.

AHAM believes that smart appliances represent the largest opportunity for the ENERGY STAR program to continue to drive market transformation and increase energy efficiencies. The traditional mindset of continually ratcheting down on machine efficiency levels is achieving fewer and fewer kilowatt-hours in savings, as opposed to the yet untapped and plentiful efficiencies that can be achieved through an integration of smart appliances and the smart grid. Smart appliances will provide energy savings. For example, when a smart appliance, such as a dishwasher, shifts residential load from peak times of day to when there is less demand for electricity, the entire system is less costly and works more efficiently. In order for smart appliances to have that impact, however, companies must be encouraged to produce them.

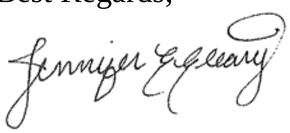
ENERGY STAR is perfectly positioned to jump start the development of the smart grid by helping to deploy smart appliances, such as dishwashers, so that consumers can start benefitting from, among a number of other benefits, lower electricity bills, energy savings, and carbon emissions reductions. At a time when dynamic pricing is implemented, these benefits will increase dramatically. AHAM, jointly with efficiency advocates, has submitted to the ENERGY

STAR program a petition seeking incentives to hasten the production of smart appliances and the development of the smart grid and to facilitate increased penetration of renewable sources of power. The petition describes potential ways in which smart appliance benefits can be incorporated into the ENERGY STAR program. We incorporate that petition, which is attached at Attachment A, and the accompanying study done by the Pacific Northwest National Laboratory (PNNL), which is attached at Attachment B, by reference in these comments.

If EPA determines it is not feasible to consider smart appliances in the current specification, we urge EPA to consider it as soon as possible in the future.

AHAM appreciates the opportunity to submit comments on the ENERGY STAR Program Requirements Product Specification for Residential Dishwashers, Eligibility Criteria, Final Draft, Version 5.0, and would be glad to further discuss these matters.

Best Regards,



Jennifer Cleary
Director, Regulatory Affairs

# ATTACHMENT A

ACEEE
American Council for an Energy-Efficient Economy

AHAM
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January 6, 2011

The Honorable Gina McCarthy
Assistant Administrator
Office of Air and Radiation
Environmental Protection Agency
1200 Pennsylvania Avenue, NW
Washington, DC 20460

The Honorable Cathy Zoi
Assistant Secretary
Office of Energy Efficiency and
Renewable Energy
U.S. Department of Energy
1000 Independence Avenue, SW
Washington, DC 20585

Dear Assistant Administrator McCarthy and Assistant Secretary Zoi:

The Association of Home Appliance Manufacturers (AHAM) and efficiency organizations, which are being coordinated by the American Council for an Energy-Efficient Economy (ACEEE), have agreed to a number of recommendations related to new appliance efficiency standards and test procedures, smart appliances, and incentives to manufacture super-efficient appliances. As part of the agreement, the parties are jointly petitioning the ENERGY STAR program to provide a 5 percent credit to the energy performance level required to meet ENERGY STAR eligibility criteria. Please find attached a petition to the ENERGY STAR program to implement one of the central pillars of the Energy Efficient and Smart Appliance Agreement of 2010.

We look forward to working with the ENERGY STAR program to advance the recommendations contained in this petition. Please do not hesitate to contact either of us if you have any questions or need any further information.

Sincerely,

Kevin Messner
Vice President, Government Relations
AHAM

Steven M. Nadel

Steven Nadel
Executive Director
ACEEE

**Joint Petition To ENERGY STAR To Adopt Joint Stakeholder Agreement As It Relates To Smart Appliances**

January 6, 2011

*Association of Home Appliance Manufacturers*[1]
*American Council for an Energy-Efficient Economy*
*Natural Resources Defense Council*
*Alliance to Save Energy*
*Alliance for Water Efficiency*
*Northwest Power and Conservation Council*
*Northeast Energy Efficiency Partnerships*
*Consumer Federation of America*
*National Consumer Law Center*
*Earthjustice*
*California Energy Commission*
*Demand Response and Smart Grid Coalition*

## I. Introduction and Overview

The Joint Petitioners are pleased to present to the U. S. Environmental Protection Agency (EPA) and Department of Energy (DOE) the results of successful negotiations which resulted in an agreement ("the Joint Proposal") on federal minimum energy conservation standards for five products, and related test procedures, ENERGY STAR, and financial incentive provisions. The description of this package and an initial estimate of its impact can be found in Attachment 1.

Central to this Joint Proposal is the agreement to request from ENERGY STAR a five percent credit to the energy performance level required to meet ENERGY STAR eligibility criteria for smart-grid enabled appliances. The Joint Petitioners urge EPA and DOE to adopt the Joint Proposal, incorporating a five percent credit to the energy performance level required to meet ENERGY STAR eligibility criteria for smart-grid enabled appliances as soon as possible, but not later than March 31, 2011. The Joint Petitioners are representative of a wide range of expert and relevant points of view—including manufacturers of various sizes representing over 99% of the market; consumer, environmental, and advocacy groups; and a major public power planning agency—concerning ENERGY STAR for the subject products.

The agreement in its entirety, *see* Attachment 2, covers residential refrigerator/freezers, clothes washers, clothes dryers, room air-conditioners, and dishwashers. There are three main pillars of this agreement:

1. *Energy efficiency standards*: the agreement recommends new federal minimum efficiency standards that will save significant amounts of energy. Lawrence Berkeley

[1] Whirlpool, General Electric, Electrolux, LG Electronics, BSH, Alliance Laundry, Viking Range, Sub-Zero Wolf, Friedrich A/C, U-Line, Samsung, Sharp Electronics, Miele, Heat Controller, AGA Marvel, Brown Stove, Haier, Fagor America, Airwell Group, Arcelik, Fisher & Paykel, Scotsman Ice, Indesit, Kuppersbusch, Kelon, DeLonghi

National Laboratory (LBL) projects that the Joint Proposed Standards would save more than 9 quads of primary energy over 30 years. It would also result in nearly five trillion less gallons of water used over 30 years and reduce carbon emissions by approximately 550 million metric tons.

2. *Smart appliances*: the agreement hastens the production of smart appliances. As part of the agreement, the parties are jointly submitting this petition to the Environmental Protection Agency (EPA) and DOE to provide a five percent credit to the energy performance level required to meet ENERGY STAR eligibility criteria for products that meet a definition of "smart appliance." Further recognizing the opportunity for smart appliances to contribute to energy efficiency and the smart grid, the parties will work together to develop a proposal for incentives for appliances with "smart" capabilities. It is expected that the incentives for smart appliances may produce additional $CO_2$ emission reductions.

3. *Tax credit*: the agreement includes recommendations for updates and extensions of the manufacturer tax credit for the production of super-efficient dishwashers, clothes washers, refrigerators and freezers. These incentives encourage manufacturers to develop, commercialize, and sell very high efficiency products, helping to transform markets faster than with standards alone. The lower tiers of the current federal incentives are phased-out under the new agreement and new, higher tiers are added. LBL has estimated the tax credits for appliances would save an additional 0.67 quads of primary energy over 30 years.

This petition is only in regard to the ENERGY STAR program (minimum efficiency standards are a part of different petitions). Action on the tax credit and energy standards elements of the agreement will require consideration by Congress and the DOE.

Congress authorized the ENERGY STAR program "to identify and promote energy-efficient products and buildings in order to reduce energy consumption, improve energy security, and reduce pollution through voluntary labeling of, or other forms of communication about, products and buildings that meet the highest energy conservation standards." 42 U.S.C. § 6294a. The Joint Proposal to provide a five percent credit to the energy performance level required to meet ENERGY STAR eligibility criteria for products that meet an EPA-set definition of "smart appliance" advances those goals. The five percent credit will encourage the design and manufacture of these products. These products have the potential to reduce energy consumption and reduce cost to consumers. Accordingly, ENERGY STAR should adopt the five percent credit.

## II. The Joint Petitioners To and Supporters of the Agreement

The American Council for an Energy Efficient Economy (ACEEE) is a nonprofit, non-partisan, organization dedicated to advancing energy efficiency as a means of promoting economic prosperity, energy security, and environmental protection. ACEEE fulfills its mission by conducting in-depth technical and policy assessments; advising policymakers and program managers; working collaboratively with businesses, public interest groups, and other organizations; publishing books, conference proceedings, and reports; organizing conferences and workshops; and educating consumers and businesses.

The Association of Home Appliance Manufacturers (AHAM) represents manufacturers of major, portable and floor care home appliances, and suppliers to the industry. AHAM's membership includes over 150 companies throughout the world. In the U.S., AHAM members employ tens of thousands of people and produce more than 95% of the household appliances shipped for sale. The factory shipment value of these products is more than $30 billion annually. The home appliance industry, through its products and innovation, is essential to U.S. consumer lifestyle, health, safety and convenience. Through its technology, employees and productivity, the industry contributes significantly to U.S. jobs and economic security. Home appliances also are a success story in terms of energy efficiency and environmental protection. New appliances often represent the most effective choice a consumer can make to reduce home energy use and costs. AHAM represents the manufacturers of virtually all affected clothes dryers and room air conditioners manufactured and/or sold in the United States. AHAM is involved in a number of activities related to smart appliances, including advocating for government action, to helping align the high level architecture and communication protocols used by smart appliances.

The Alliance to Save Energy (ASE) is a coalition of prominent business, government, environmental, and consumer leaders who promote the efficient and clean use of energy worldwide to benefit consumers, the environment, the economy, and national security. Established as an NGO in 1977, to carry out its mission the Alliance undertakes research, educational programs, and policy advocacy; designs and implements energy-efficiency projects; promotes technology development and deployment; and builds public-private partnerships in the United States and other countries.

The Alliance for Water Efficiency is a stakeholder-based 501(c)(3) non-profit organization dedicated to the efficient and sustainable use of water, with 317 member organizations from water utilities, government agencies, businesses, industry, plumbing, appliance and irrigation manufacturers, retailers, environmental and energy efficiency advocates, and other stakeholders. Located in Chicago, the Alliance serves as a North American advocate for water efficient products and programs, and provides information and assistance on water conservation efforts.

The Appliance Standards Awareness Project (ASAP) is a coalition group dedicated to advancing cost-effective energy efficiency standards for appliances and equipment. ASAP works at both the state and federal levels and is led by a Steering Committee with representatives from consumer groups, utilities, state government, environmental groups, and energy-efficiency groups.

The Consumer Federation of America is an association of nearly 300 nonprofit consumer groups that was established in 1968 to advance the consumer interest through research, advocacy, and education.

The National Consumer Law Center ®, a nonprofit corporation founded in 1969, assists consumers, advocates, and public policy makers nationwide on consumer law issues. NCLC works toward the goal of consumer justice and fair treatment, particularly for those whose poverty renders them powerless to demand accountability from the economic marketplace. NCLC has provided model language and testimony on numerous consumer law issues before federal and state policy makers. NCLC publishes an 18-volume series of treatises on consumer law, and a number of publications for consumers.

The Natural Resources Defense Council (NRDC) is a national environmental advocacy organization with over 1.3 million members and online activists.  NRDC has spent decades working to build and improve DOE's federal appliance standards programs because of the important energy, environmental, consumer, and reliability benefits of appliance efficiency standards.  NRDC participated in the enactment of the first federal legislation establishing efficiency standards, and has been active in all significant rulemakings since then.

Northeast Energy Efficiency Partnerships (NEEP) is a non-profit organization that facilitates regional partnerships to advance the efficient use of energy in homes, buildings and industry in the Northeast U.S.  NEEP works to leverage knowledge, capability, learning and funding through regionally coordinated policies, programs and practices.  As a regional organization that collaborates with policy makers, energy efficient program administrators, and business, NEEP is a leader in the movement to build a cleaner environment and a more reliable and affordable energy system.

The Northwest Power and Conservation Council is an interstate compact between the states of Idaho, Montana, Oregon and Washington authorized by the Northwest Power Act of 1980 (PL96-501). The Council is charged with ensuring that the Northwest's electric power system will provide adequate and reliable energy at the lowest economic and environmental cost to its citizens.

The Demand Response and Smart Grid Coalition (DRSG) is the trade association for companies that provide products and services in the areas of demand response, smart meters and smart grid technologies.  DRSG works to educate and provide information to policymakers, utilities, the media, the financial community and stakeholders on how demand response and smart grid technologies such as smart meters can help modernize our electricity system and provide customers with new information and options for managing their electricity use.

Other supporters include the California Energy Commission and Earthjustice.

## III. **Rationale For The Negotiations**

The Joint Petitioners entered into discussions on smart appliances as part of the overall agreement negotiation for two main reasons. First, it was thought that the smart grid can provide important energy efficiencies and reliability improvements and that there needs to be incentives to manufacturers to sell smart appliances to hasten the development of an effective smart grid. Second, smart appliances can provide more effective and efficient use of electricity, which can save energy, save consumers money on their electricity bills, and increase the use of renewable energy. The Joint Petitioners believe that both of these goals were achieved and will be borne out in the implementation of this proposal.

## IV. **The Negotiations Process**

The parties' discussions commenced in the spring of 2010 and an agreement was finalized on July 30, 2010. Discussions were held, and empirically- and technically-based proposals were made relying on data and analysis provided by DOE's consultants. The Joint Petitioners' proposal also is supported by the Pacific Northwest National Laboratory's analysis on benefits of smart appliances, as discussed below.

## V. **The Joint Stakeholder Proposal**

The Joint Proposal is to provide a five percent credit to the energy performance level required to meet ENERGY STAR eligibility criteria for the smart-grid enabled appliances that are included in the Joint Proposal, which includes residential refrigerator/freezers, clothes washers, clothes dryers, room air-conditioners, and dishwashers. A five percent credit means that smart appliances would be allowed to use five percent more energy than non-smart products that earn the Energy Star designation.[2] The proposal will save consumers money and save energy, and may help increase the use of renewable energy.

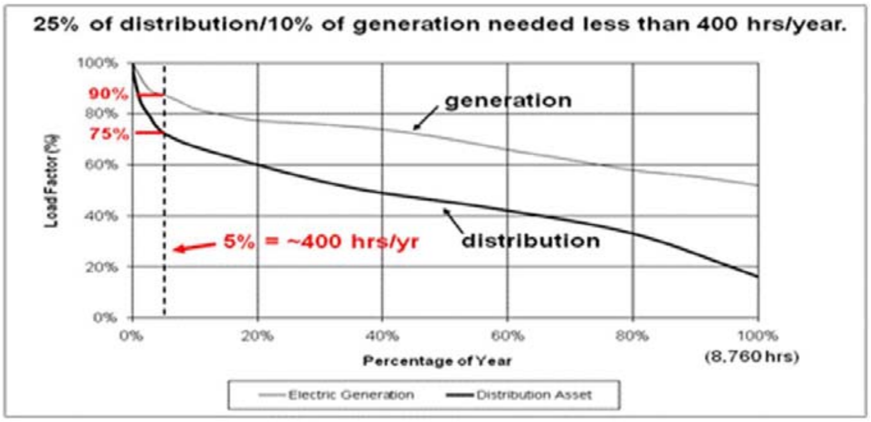
## VI. **Justification**

### A. The Problem: Electricity Use Is Increasing

EIA, in its 2010 *Annual Energy Outlook*, projects that electricity use will increase by more than 30 percent by 2035. Residential electricity use will increase by 23 percent from 2010-2035, due to growth in population and disposable income and continued population shifts to warmer regions with greater cooling requirements. Peak demand increases may be even more pronounced. One industry forecast of peak demand, which extrapolates the North American Electric Reliability Corporation's 2005 Peak Demand and Energy Projection Bandwidths, results in non-coincident peak demand that is 55 percent higher in 2030 than it was expected to be in

[2] Please note that the joint agreement and this petition does not cover what the Energy Star specification should be for non-smart appliances, against which the 5% credit would be calculated.

2008.[3] Summer peak load was expected to increase 430 GW in 2030 from the existing 781 GW. This forecast DOES NOT include expected demand response programs, but does include modest forecasted efficiency savings. Peak demand is the most costly because 10 percent of the generation and 25 percent of the transmission infrastructure are needed to service only 400 hours per year (see figure 1). However, the 2010 Annual Energy Outlook projects that electric power sector generating capacity will grow by only 8 percent from 2010 to 2030.




*Source: Pacific Northwest National Laboratory*

**Figure 1**

B. <u>The Smart Grid Is Critical in Addressing the Increase in Electricity Use</u>

As discussed below, the smart grid is an important part of efforts to address projected increases in electricity use. The Electric Power Research Institute (EPRI) estimates that the implementation of smart grid technologies could reduce electricity use by more than four percent annually by 2030.[4] And the residential sector is critically important to managing the electrical grid into the future. The residential sector represents 37 percent of electricity use and is the largest consuming sector of electricity (see figure 2).

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[3] Ingrid Rohmund and Greg Wikler (Global Energy Partners, LLC), Ahmad Faruqui (The Brattle Group), Omar Siddiqui (Electric Power Research Institute) and Rick Tempchin (Edison Electric Institute), "Assessment of Achievable Potential for Energy Efficiency and Demand Response in the U.S. (2010 – 2030)," Paper prepared for 2008 ACEEE Summer Study on Energy Efficiency in Buildings, p. 5-264.

[4] Press Release, U.S. Department of Energy, Secretary Chu Announces Two Million Smart Grid Meters Installed Nationwide (August 31, 2010), *available at* http://www.energy.gov/news/9433.htm.

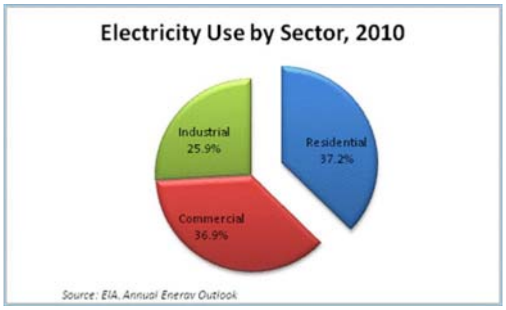


**Figure 2**

Demand response, augmented by the smart grid and smart appliances, will result in some energy savings and reductions in costs. The North American Energy Standards Board (NAESB) has defined demand response as "changes in electric use by demand-side resources from their normal consumption patterns in response to changes in the price of electricity, or to incentives designed to induce lower electricity use at times of potential peak load, high cost periods, or when systems reliability is jeopardized." [5] In other words, when an electric utility company or third party energy service provider encounters a problem, it can send a signal alerting the consumer of the complication so that the consumer can react by reducing load during this critical time period. Reduction in energy usage during critical periods is the result of a response to a request for lowered energy usage. Critical time reductions of energy use can be accomplished by either "shifting" usage to a non-critical time of the day or by "shedding" load to reduce peak power.

According to EPRI ". . . load reductions offered by demand response and load control programs facilitated by a Smart Grid can yield energy savings and reductions in carbon emissions."[6] And Secretary Chu has recognized that "[s]mart grid technologies will give consumers choice and promote energy savings, increase energy efficiency, and foster the growth of renewable energy resources."[7] Further evidence that reducing peak power is linked to saving energy, in the EIA's Electric Power Annual 2008 (Table 9.2) utilities reported for every 1kW of peak load reduction there is a corresponding 139 kWh of energy saved.

Reducing peak load provides several other benefits:

- provides relief during capacity-constrained periods
- reduces transmission congestion
- minimizes operation of peaking plants
- defers the need for new generation

According to a report released by Vice President Biden on August 24, 2010:

[5] "Measurement & Verification for Demand Response Programs," Recommendation to NAESB Executive Committee (July 29, 2009).

[6] "The Green Grid," Electric Power Research Institute, June 2008

[7] Press Release, U.S. Department of Energy, Secretary Chu Announces Two Million Smart Grid Meters Installed Nationwide (August 31, 2010), *available at* http://www.energy.gov/news/9433.htm.

> *Smart Grid technology, combined with supportive policy, allows for smarter use of energy, largely by increasing the transparency, measurement, and control of energy used by the players who supply, transmit, distribute, and demand it. Through automated sensors and controls as well as dynamic pricing, this intelligent infrastructure will make the electric system more reliable, empower consumers and utilities to use energy more wisely, help manage peak demand, enable larger scale use of renewable energy and electric vehicles, and reduce U.S. dependence on oil.*[8]

The Joint Petitioners' proposal for a five percent credit is exactly the type of supportive policy that will allow the smart grid to thrive and produce the above-enumerated benefits for consumers, utilities, and the environment.

C. Smart Appliances Benefit Spinning Reserves

To balance supply and demand continuously despite sudden, unexpected failures of generators and/or transmission lines, utilities typically maintain contingency reserves to compensate for such failures. Contingency reserves include: 10-minute spinning reserves, 10-minute non-synchronized reserves, and 30-minute operating reserves. The 10-minute spinning reserves are typically provided by generators supplying base-load power by operating the generators below their rated capacity, and then ramping them up when called upon to deliver spinning reserves. Despite their importance to power system operation, the larger the spinning reserve requirement, the greater the emissions.

In recent years, there has been considerable interest towards exploiting the enormous potential of demand response towards providing spinning reserves.[9] This is over and beyond peak-load reduction as discussed above. Residential loads capable of interacting with the grid (smart appliances) such as refrigerator/freezers, clothes washers, clothes dryers, room air-conditioners, and dishwashers are particularly suited as sources of 10-minute spinning reserves because the operation of such loads can be interrupted for short periods (up to 10 minutes) without causing any diminution of the quality of service for consumers. Furthermore, end-use load can often be curtailed almost instantaneously as opposed to generators that must ramp up and down subject to operating constraints in order to avoid equipment damage. Finally, given the potentially large number of responsive end-use loads, their aggregate response could be extremely reliable when called upon to provide spinning reserves. Thus, residential loads could obviate the need for maintaining some fossil-fuel based generation for providing spinning reserves thereby reducing operating costs and also lowering emissions.

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[8] Executive Office of the President of the United States and Vice President of the United States, "The Recovery Act: Transforming The American Economy Through Innovation," at 37 (August 2010), available at http://www.whitehouse.gov/sites/default/files/uploads/Recovery_Act_Innovation.pdf (emphasis added) [hereinafter "the Recovery Act Report"].

[9] Spinning Reserve From Responsive Load: http://certs.lbl.gov/pdf/spinning-reserves.pdf

Pacific Northwest National Laboratory (PNNL) has undertaken a study to evaluate the precise benefits of smart appliances towards providing both peak-load reduction and spinning reserves. An overview of this study is presented in Section E.

D. Definition of Smart Appliances and Product-specific Guidance

Defining smart appliances is challenging because it is a definition for a product that is still in its infancy, and a major purpose of this petition is to provide an incentive to increase the deployment across the country. Hence, it is important to clearly define the properties and capabilities of a 'Smart Appliance' to differentiate it from existing home appliances and ensure that the definition is not so restrictive that it stifles technology innovation and competition. The Joint Petitioners propose the following provisional definition of smart appliances:

Smart appliances are still in their infancy, presenting a significant definitional challenge. The Joint Petitioners believe it is important to clearly differentiate smart appliances from existing home appliances by defining smart appliance properties and capabilities. However, definitions must not be so restrictive as to stifle technology innovation and competition. The products must continue to comply with the applicable product safety standards -- the addition of smart technology cannot override existing safety protections and functions. Any reduction in load cannot adversely impact the product's inputs, e.g., clothes, foods, dishware.

The Joint Petitioners propose the following provisional definitions related to smart appliances. Any smart appliance must meet the definition of "smart appliance" and the product specific requirements below.

> **The term "smart appliance"** means a product that uses electricity for its main power source which has the capability to receive, interpret and act on a signal received from a utility, third party energy service provider or home energy management device, and automatically adjust its operation depending on both the signal's contents and settings from the consumer. The product will be sold with this capability, which can be built-in or added through an external device that easily connects to the appliance. The costs of such devices shall be included in the product purchase price.[10]
>
> These signals must include (but are not limited to) appliance delay load, time-based pricing and notifications for load-shedding to meet spinning reserve requirements. Any appliance operation settings or modes shall be easy for an average, non-technical consumer to activate or implement. Additionally, a smart appliance or added device may or may not have the capability to provide alerts and information to consumers via either visual or audible means. The appliance may not be shipped with pre-set time duration limits that are less than those listed below, but may allow consumer-set time duration

[10] If additional requirements are needed to activate the product's "smart" capabilities as purchased, then prominent labels and instructions must be displayed at the point of purchase and in product literature on what specifically consumers or utilities need to do to achieve these capabilities (e.g. "This product requires snapping in the compatible network module and utility installation of a smart meter or other device for use of capabilities that earned the ENERGY STAR label").

limits on smart operating modes, and will also allow consumers to override any specific mode (e.g. override a delay to allow immediate operation, limit delays to no more than a certain number of hours, or maintain a set room temperature).

**The term "delay load capability**" refers to the capability of an appliance to respond to a signal that demands a response intended to meet peak load deferral requirements, but which also could be used to respond to a sudden maintenance issue at another time of day.

**The term "spinning reserve capability"** means the capability of an appliance to respond to a signal that demands a response intended to temporarily reduce load by a short-term, specified amount, usually 10 minutes.

We further recommend product-specific definitions as provided below. Each of the following definitions includes a response to a "delay load signal" and a response to reduce load to provide spinning reserve services. A smart appliance needs to have the capability to meet both of these requirements, but not simultaneously.

a) Refrigerator/Freezers: a smart refrigerator/freezer must have the following minimum capabilities-

i) Delay load capability - upon receipt of a signal requesting a delay of load for a time duration not exceeding 4 hours, the product must shift defrost cycles beyond the delay period and do one of the following --

(1) shift ice maker cycles beyond the delay period, or

(2) reduce average wattage during the delay period by at least 9.6 watts relative to average load over a 24 hour period, and may shift this wattage beyond the delay period", and

ii) Spinning reserve capability - upon receipt of a signal requesting the start of a reduced load period for a time duration not exceeding 10 minutes, the product must restrict its average energy consumption during this time period to a maximum of 50 percent of the average load over a 24 hour period (unless there is a consumer initiated function, such as door opening or ice or water dispensing).

b) Clothes Washers: a clothes washer must have the following minimum capabilities -

i) Delay load capability - upon receipt of a signal requesting a delay of load for a time duration not exceeding either 4 hours or such other period that the consumer may select, the product must automatically delay the start of the operating cycle beyond the delay period, and

ii) Spinning reserve capability - upon receipt of a signal requesting the start of a reduced load period for a time duration not exceeding 10 minutes, the product must automatically reduce its average wattage during this time period by at least 50 percent relative to average wattage during this period in the operating cycle under DOE test conditions.

c) Clothes Dryers: a clothes dryer must have the following minimum capabilities -

i) Delay load capability - upon receipt of a signal requesting a delay of load for a time duration not exceeding 3 hours, the product must automatically delay the start of the operating cycle beyond the delay period, and

ii) Spinning reserve capability - upon receipt of a signal requesting the start of a reduced load period for a time duration not exceeding 10 minutes, the product must automatically reduce its average wattage during this period by at least 80 percent relative to average wattage during this period in the operating cycle under the DOE test conditions.

d) Room Air Conditioners: a room air conditioner must have the following minimum capabilities -

i) Delay load capability - upon receipt of a signal requesting a delay of load for a time duration not exceeding either 4 hours or such other period that the consumer may select, the product must automatically reduce its average wattage during this period by at least 25 percent relative to average wattage during this period in the operating cycle under the DOE test conditions, and

ii) Spinning reserve capability - upon receipt of a signal requesting the start of a reduced load period for a time duration not exceeding 10 minutes, the product must automatically reduce its average wattage during this period by at least 80 percent relative to average wattage during this period in the operating cycle under during the DOE test conditions.

e) Dishwashers: a dishwasher must have the following minimum capabilities-

i) Delay load capability - upon receipt of a signal requesting a delay of load for a time duration not exceeding either 4 hours or such other period that the consumer may select, the product must automatically delay the start of the operating cycle beyond the delay period , and

ii) Spinning reserve capability - upon receipt of a signal requesting the start of a reduced load period for a time duration not exceeding 10 minutes, the product must automatically reduce its average wattage during this period by at least 50 percent relative to average wattage during this period in the operating cycle under the DOE test conditions.

## E. Benefits of Smart Appliances

PNNL has undertaken a study to evaluate the precise benefits of smart appliances (refrigerator/freezers, clothes washers, clothes dryers, room air-conditioners, and dishwashers) towards providing both peak-load reduction and spinning reserves through demand response. The benefits being considered are distinct from those arising due to traditional machine enhancements that enable operational efficiencies. The benefits include estimates of the production cost savings to utilities and the extent to which smart appliances can provide ancillary services to facilitate greater penetration of renewable generation sources (wind and solar in particular).

The analytical model developed by PNNL is based on generic smart appliance demand response capabilities, i.e., not limited to a particular manufacturer. The methodology adopted is based on various underlying parameters such as expected smart appliance penetration and usage rates, daily usage patterns, definitions of peak and off-peak periods, and other pertinent benefits-impacting assumptions. In establishing the monetary value of benefits, historical wholesale market clearing prices are drawn from various electric power markets including NYISO, CAISO, PJM, and ERCOT.

The model is based on ELCAP load shapes for daily usage patterns. [11] Appliance energy consumption is based on AHAM data and DOE standards and test procedures.[12] The valuation of benefits is different for each appliance, but for dryers, clothes washers, and dishwashers, the model first estimates the total on-peak and off-peak consumptions. Then, based on these consumptions, and annual hourly average energy market clearing prices, the wholesale production cost savings derived from shifting of a given percentage of peak load to off-peak periods is estimated. When it comes to spinning reserves, there are 3 components.

1. Load from dryers, clothes washers, and dishwashers that are operating during off peak.
2. Appliance loads not shifted from peak hours. Recall, only a certain percentage of loads are shifted from peak to off-peak hours. The remaining load during peak hours is available for spinning reserves.
3. Load shifted from peak to off-peak hours. This shifted load is also available for spinning reserves.

The annual hourly spinning-reserve market clearing prices are invoked to value these three spinning reserve components. The total operational cost savings or "benefits" are those arising from peak load shifting and spinning reserves.

The five percent smart appliance credit is then applied to the total annual operating cost of a given appliance to estimate the credit which is the "cost" applied towards making an appliance smart. Finally, the "benefits" to "cost" ratio is evaluated. The optimistic scenario generally assumes that all customers can receive grid signals and communicate these to the appliance and that all customers are willing to shift 100 percent of their on-peak loads. The pessimistic scenario generally assumes that 50 percent of customers can receive grid signals and communicate these to the appliance, that 70 percent of customers are willing to shift on-peak loads (90 percent in the case of the 10 minute shifts needed to serve spinning reserves), and that on average these customers will shift about 50 percent of their on-peak load out of the peak. The optimistic scenario assumes that shifts will move energy use out of a five-hour peak period on average, while the pessimistic scenario uses a four-hour average for shifts. A summary of the results are as follows and full report is attached:

> *As can be seen from **Table 1.1** and **Table 1.2**, in all the markets, in either optimistic or pessimistic assumption scenarios, the benefit-to-cost ratio for all appliances exceeds 100 percent. This is especially the case for the optimistic scenario, in which the benefits overwhelmingly exceed the cost as shown in **Table 1.1**. This means that the annual benefits from having smart grid capabilities in an appliance are greater than an equivalent five percent increase in operational machine efficiencies. The expectation then is that if ENERGY STAR adopts this proposal for a five percent incentive for smart appliances it will facilitate the growth of the smart-appliance industry.*

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[11] Pratt, R.G., et al., 1989. "Description of Electric Energy Use in Single-Family Residences in the Pacific Northwest," End-Use Load and Consumer Assessment Program (ELCAP)," Pacific Northwest Laboratory, DOE/BP-13795-21, Richland, WA, April 1989

[12] http://www1.eere.energy.gov/buildings/appliance_standards/residential_products.html

**Table 1.1**: Benefit-to-Cost Ratios of Smart Appliances Based on "Optimistic" Assumptions

| | DW | CW | RAC | Freezer | Refrigerator | Dryer |
|---|---|---|---|---|---|---|
| PJM 2006 | 528% | 563% | 733% | 539% | 536% | 680% |
| ERCOT 2008 | 817% | 871% | 1060% | 881% | 877% | 1054% |
| NYISO 2008 | 367% | 403% | 585% | 357% | 355% | 462% |
| NYISO 2006 | 353% | 389% | 712% | 346% | 344% | 442% |
| CAISO 2008 | 319% | 356% | 554% | 313% | 312% | 396% |

**Table 1.2**: Benefit-to-Cost Ratios of Smart Appliances Based on "Pessimistic" Assumptions

| | DW | CW | RAC | Freezer | Refrigerator | Dryer |
|---|---|---|---|---|---|---|
| PJM 2006 | 136% | 134% | 131% | 150% | 150% | 207% |
| ERCOT 2008 | 203% | 200% | 295% | 230% | 228% | 337% |
| NYISO 2008 | 107% | 106% | 139% | 112% | 111% | 147% |
| NYISO 2006 | 112% | 112% | 160% | 119% | 118% | 160% |
| CAISO 2008 | 99% | 100% | 135% | 102% | 101% | 134% |

F. Synergies of Suite of Appliances

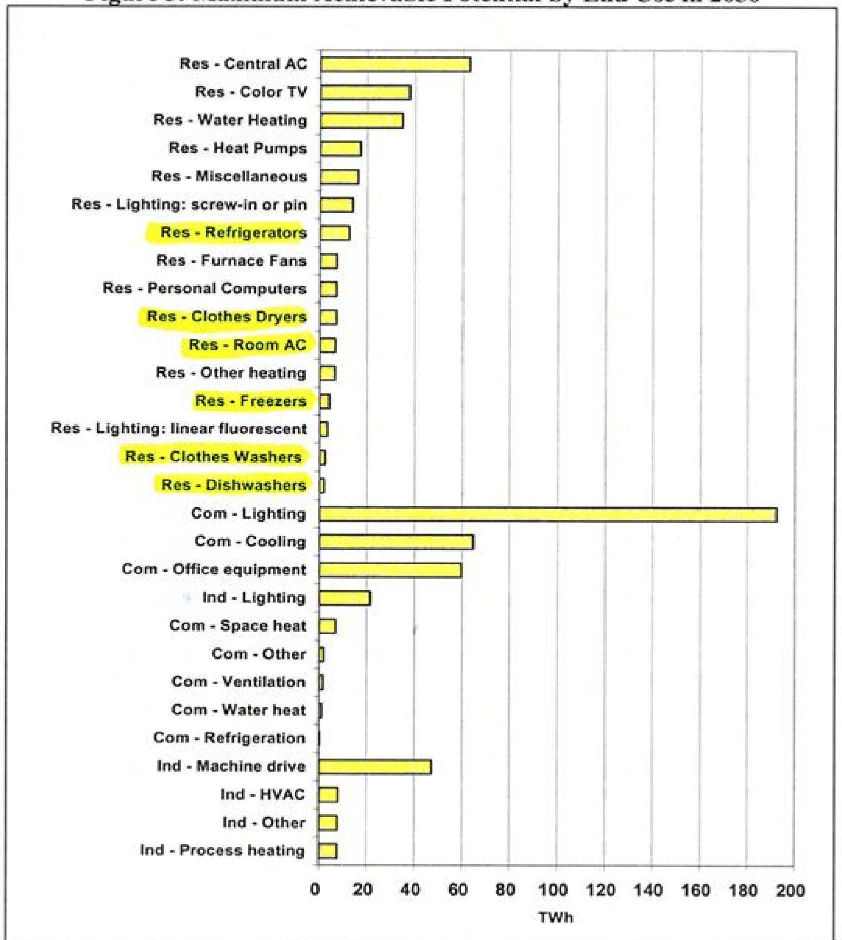
The benefits of smart appliances are greatly enhanced by the synergies provided by having multiple smart appliances in the home, hence the need for an across the board five percent credit to equally incentivize the deployment and use of "smart" features in all the products. For example, a suite of appliances in the home can better "represent" a power generation facility because of its flexibility to address load shifting and spinning-reserve requirements. Different products may provide strengths in different areas. For example, a refrigerator would likely have a high probability that its defrost operation would be shifted to a more desirable time (at any time of day or night) for the grid operations when needed, whereas a dryer, with its high load during a relatively short span of time usually during the day, would likely have a higher probability that its heat elements could be turned off or reduced for short periods of time during operation to reduce spinning reserve requirements. Thus, the synergies of a home suite with a broad mix of smart appliances would likely provide a correspondingly higher benefit to the environment, the consumer and the grid, than the additive benefits of each smart appliance evaluated separately.

G. Demand Response vs. Energy Efficiency

Increasing energy efficiency is not the only way to drive energy savings. As discussed above, demand response can also yield some energy savings. For example, cycling the dryer heating coil off while continuing to spin clothes allows use of the residual heat in the dryer, reducing heater-on time when the heater coil is restarted and yielding less total cycle energy use but a longer cycle time. The residential consumer and smart appliances are important to the success of demand response. Since late 2007 and after passage of the 2007 energy law, for example, efficiency savings were estimated by the Electric Power Research Institute (EPRI), including savings from refrigerators, dryers, room air conditioners, clothes washers, and dishwashers. EPRI found that the savings from these appliances were a small percentage of maximum achievable potential in 2030 in relation to other residential, commercial, and industrial uses.[13] Efficiency advocates believe that EPRI significantly underestimated the efficiency savings available from appliances (e.g., EPRI generally only looked at then-current Energy Star levels and not beyond). Still, efficiency advocates agree that as appliance efficiency continues to increase, remaining opportunities for appliance efficiency savings will decline Further information from the EPRI study is shown in Figure 3, which depicts that the maximum potential for efficiency savings in home appliances (highlighted in chart) that are affected by this petition is quite low compared with other products.

[13] Rohmund, Ingrid ,et. al (Global Energy Partners, Brattle Group, EPRI, EEI), Assessment of Achievable Potential for Energy Efficiency and Demand Response in the US (2010-2030)

Figure 5: Maximum Achievable Potential by End Use in 2030




Source: Electric Power Research Institute et al. (2008) – preliminary estimates June 2008

**Figure 3**

According to the EPRI assessment of achievable potential for energy efficiency and demand response in the U.S., demand response combined with increases in energy efficiency can offset 40 percent (173 GW) of the growth in summer peak demand by 2030 (see figure 4).[14]

[14] Ibid

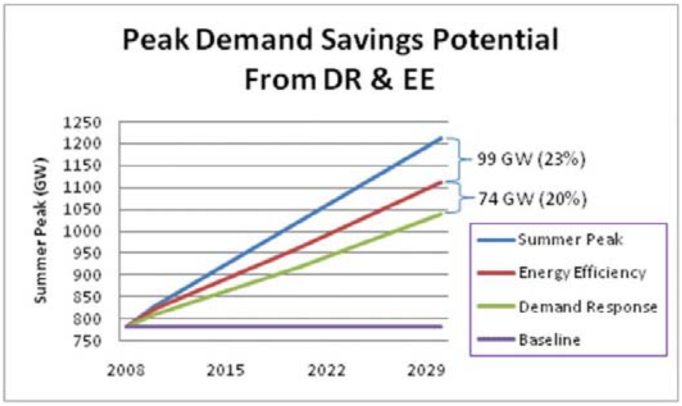
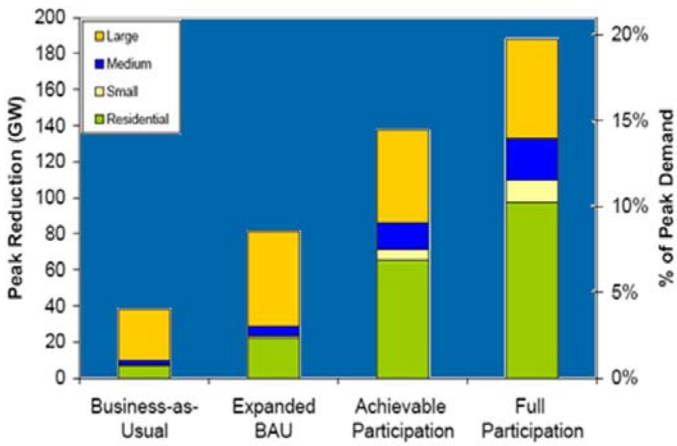



**Figure 4**

Significantly, residential customers offer as much demand response potential as small, medium, and large businesses combined (see figure 5).




*Source: Federal Energy Regulatory Commission*

**Figure 5**

According to FERC, ". . . it is the residential class that represents most [sic] untapped potential for demand response. . . While residential customers provide only roughly 17 percent of today's demand response potential, in the AP [Achievable Participation] scenario they provide over 45 percent of the potential impacts."[15] The FERC National Assessment of Demand Response, June 2009, found that "pricing w/tech," (including smart appliances) offer more than half of the potential for peak demand reduction (see figure 6). Furthermore, as the PNNL study indicates, further gains are possible through the utilization of smart appliances for providing spinning reserves.

[15] "National Assessment of Demand Response," Federal Energy Regulatory Commission, June 2009

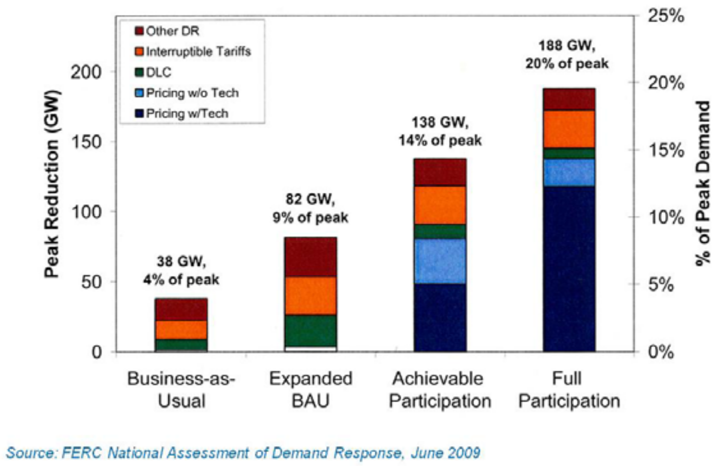



**Figure 6**

H. Smart Appliances Are Untapped

It is expected that an increasing number of consumers will have access to smart meters over the next five years. According to the Recovery Act Report:

> . . . the Recovery Act recognized the opportunity to accelerate the deployment of components that make up a Smart Grid to support a modern, low-carbon economy and create a platform for innovation for new energy management and information services in homes and buildings. The combination of Recovery Act funds and private investments promise to add 18 million new smart meters to the eight million currently in use. This means 26 million smart meters will be in use by 2010, on track to reach 40 million by 2015 through public and private investment.[16]

However, in order for consumers to maximize the benefits they can obtain from these smart meters, it is important to incentivize the use of smart appliances in the home. The Joint Petitioners' proposed five percent credit will jump start this component of the smart grid, thus helping to achieve energy and other savings on an accelerated timeline.

I. Demand Reduction Yields Further Capacity Savings

Reducing demand also yields capacity savings. Reducing demand may have a 24 percent higher impact at the generating facility, which equates to even more capacity savings (see figure 7).

[16] The Recovery Act Report, *supra* n.4, at 39.

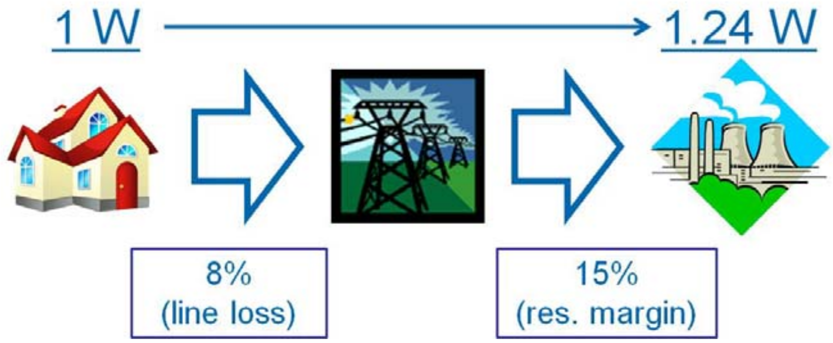



**Figure 7** *(Source: The Brattle Group, Power of 5%)*

J. Increased Use of Renewable Energy

The benefit of the smart grid goes beyond energy savings. Due to environmental concerns, there has been increasing interest in recent years towards incorporating large amounts of renewable sources of energy such as solar and wind, and diminish the reliance on fossil-fuels to create a more diversified energy supply portfolio. For example, DOE has initiated a collaborative effort to explore the possibility of wind power supplying 20 percent of US electricity needs by the year 2030.[17] One of the key challenges involved with solar and wind as sources of energy is that they are intermittent and cannot be relied upon with certainty. Solar energy output can drop very quickly with passing clouds, while wind energy output changes very frequently, almost every hour. As a result, in order to balance supply and demand, a key objective of power system operation alluded to above, it is required to maintain energy reserves based on conventional generation sources like natural gas. But doing so works against the very purpose of incorporating solar and wind energy, namely, decreasing reliance on fossil fuels. Fortunately, demand response through smart appliances can be invoked to curtail and/or defer demand for power during periods when solar and wind energy are in short supply, and to shift the demand to when there is an abundance, enabling greater utilization of renewable energy.

Thus, smart appliances and smart grid can play an important role in facilitating greater utilization of intermittently available renewable resources such as solar and wind, from which will accrue reductions in $CO_2$ emissions.[18] The intermittent nature of the renewables is a critical impediment to greater impact. By developing a truly smart grid that can shift demand to when supply is available, this impediment gets reduced significantly. A dynamic response system like that envisioned for residential usage of smart appliances will enable renewable energy to become a more significant part of the total energy picture. This five percent energy credit for being smart grid enabled may be critical to increasing the use of renewable energy.

[17] http://www1.eere.energy.gov/windandhydro/wind_2030.html

[18] "The Green Grid," Electric Power Research Institute, June 2008

## K. Smart Appliances Will Also Help Reduce Carbon Emissions

Recently, PNNL published a study that estimates the role of smart grid towards reducing carbon emissions.[19] In particular, the study evaluated the carbon reductions through nine smart grid mechanisms. PNNL found that carbon emissions can be reduced directly through smart grid applications, and indirectly by investing the operational savings resulting from smart grid into renewable sources of power generation and efficiency programs. The table below (see figure 8) summarizes the study's findings including the key conclusion: smart grid may facilitate a 12 percent direct carbon reduction, and a 6 percent indirect reduction.

| Mechanism | Electric Sector Energy $CO_2$ Reductions | |
|---|---|---|
| | Direct | Indirect |
| Conservation Effect of Consumer Information and Feedback Systems | 3% | - |
| Joint Marketing of Efficiency and Demand Response Programs | - | 0% |
| Diagnostics in Residential and Small/Medium Commercial Buildings | 3% | - |
| Measurement and Verification for Efficiency Programs | 1% | 0.5% |
| Shifting Load to More Efficient Generation | < 0.1% | - |
| Support Additional Electric Vehicles (EVs) / Plug-In Hybrid Electric Vehicles (PHEVs) | 3% | - |
| Conservation Voltage Reduction and Advanced Voltage Control | 2% | - |
| Support Penetration of Solar Generation (RPS > 25%) | (1) | (2) |
| Support Penetration of Wind Generation (25% RPS) | < 0.1% | 5% |
| **Total, Share of U.S. Electric Sector Energy and $CO_2$ Emissions** | **12%** | **6%** |

**Figure 8. Nine Smart Grid based Carbon Reducing Mechanisms (Source: PNNL The Smart Grid: An Estimation of the Energy and CO2 Benefits)**

The PNNL study does not explicitly identify the role of smart appliances in carbon reductions, but smart appliances could play a role in several of the carbon reducing mechanisms in the above table.

## L. Smart Appliances Will Help Consumers Save Money

Smart appliances will also benefit the consumer. "The development of [smart grid tools for consumers] will enable both utilities and consumers to use electricity more efficiently, thereby reducing their costs."[20] For example, dynamic pricing of electricity creates the conditions that encourage consumers to change their or the appliances' behavior by using appliances when the

[19] Smart Grid: An Estimation of the Energy and CO2 Benefits, presentation to EPA, http://www.epa.gov/statelocalclimate/documents/pdf/pratt_presentation_3-23-2010.pdf

[20] The Recovery Act Report, *supra* n.4, at 40.

rates are lower, which if properly developed, will save consumers money on their total electricity bill. According to FERC's Assessment of Demand Response and Advanced Metering Report, there were an estimated 7.95 million installed advanced meters nationwide in 2009. These smart meters are already helping to reduce energy costs for families and businesses.[21] As stated above, EPRI estimates that the implementation of smart grid technologies could reduce electricity use by more than four percent annually by 2030, which would mean an electric bill savings of $20.4 billion for consumers and businesses around the country each year.[22]

## VII. **Conclusion**

The Joint Petitioners recommend that the EPA and DOE adopt the Joint Proposal, providing a 5 percent credit to the energy performance level required to meet ENERGY STAR eligibility criteria for smart-grid enabled appliances contained in the Joint Proposal. We believe that the broad consensus in support of the proposed credit will allow ENERGY STAR and the consumers to benefit from smart appliances and the smart grid more quickly, avoiding lost energy savings and savings on electricity bills. We urge EPA and DOE to expedite the adoption of this proposal on as accelerated a schedule as possible, but preferably no later than March 31, 2011.

Joint Petitioners

Manufacturers

Kevin Messner
Vice President, Government Relations
Association of Home Appliance Manufacturers

Advocates

Steven Nadel
Executive Director
American Council for an Energy Efficient Economy

*On Behalf of –*

[21] Press Release, U.S. Department of Energy, Secretary Chu Announces Two Million Smart Grid Meters Installed Nationwide (August 31, 2010), *available at* http://www.energy.gov/news/9433.htm.

[22] *Ibid.*

*Members of Major Appliance Division:*
*Whirlpool*
*General Electric*
*Electrolux*
*LG Electronics*
*BSH*
*Alliance Laundry*
*Viking Range*
*Sub-Zero Wolf*
*Friedrich A/C*
*U-Line*
*Samsung*
*Sharp Electronics*
*Miele*
*Heat Controller*
*AGA Marvel*
*Brown Stove*
*Haier*
*Fagor America*
*Airwell Group*
*Arcelik*
*Fisher & Paykel*
*Scotsman Ice*
*Indesit*
*Kuppersbusch*
*Kelon*
*DeLonghi*

*Appliance Standards Awareness Project*
*Natural Resources Defense Council*
*Alliance to Save Energy*
*Alliance for Water Efficiency*
*Northwest Power and Conservation Council*
*Northeast Energy Efficiency Partnerships*
*Consumer Federation of America*
*National Consumer Law Center*

ATTACHMENT I

# Energy Efficient and Smart Appliance Agreement of 2010

# Supporters

Association of Home Appliance Manufacturers
American Council for an Energy-Efficient Economy
Appliance Standards Awareness Project
Natural Resources Defense Council
Earthjustice
Alliance to Save Energy
Northwest Power and Conservation Council
Northeast Energy Efficiency Partnerships
California Energy Commission
Demand Response and Smart Grid Coalition
Consumer Federation of America
National Consumer Law Center
Alliance for Water Efficiency

# Agreement Overview

**SAVES ENERGY/INCREASES ENERGY INDEPENDENCE**

- Improves product energy efficiency and saves more than 9 Quads of energy over 30 years (U.S. uses ~100 quads)

**SAVES WATER**

- Requires and incentivizes clothes washers and dishwashers to use nearly 5 trillion less gallons of water over 30 years

**REDUCES GHG EMISSIONS**

- 30-year savings ~550 MMT CO2

**SAVES CONSUMERS MONEY**

- Net savings to consumers in the billions of $

**SMART GRID AND ENERGY STAR**

- Jump-starts the Smart Grid by helping to deploy smart appliances nationwide and enable consumers to better take advantage of demand-response and real-time pricing opportunities
- Recognizes smart appliance contributions through ENERGY STAR

# Agreement Overview

**JOBS**

- Impacts 46,000 manufacturing jobs (19,000 direct; 27,000 supply chain/support) and creates new jobs, including bringing back to the US jobs that were outsourced in earlier years

**MANUFACTURER INCENTIVES**

- Incentivizes manufacturers to increase the production of super-efficient products—over and above ENERGY STAR levels—thereby saving even more energy and water and encouraging more job creation

**DOE EFFICIENCIES**

- Frees up resources now devoted to rulemakings on these products

# New Refrigerator Standards

- 20-30% energy savings relative to current
- New standards take effect Jan. 1, 2014
- DOE to develop new test procedure to measure ice-maker energy use by Dec. 31, 2012.  This is used for standard effective ~2016.

# Refrigerator/Freezer Energy Savings by Category

| % Savings | Classes |
|---|---|
| 30% | Auto defrost freezers |
| 25% | Top-mount and side-by-side R/F<br>Manual defrost freezers |
| 20% | Bottom-mount R/F |
| 10-25% | Various smaller categories |
| | Standards are 5% lower for built-in units |

# New Clothes Washer Standards

- Initial standards effective Jan. 1, 2015
- Different standards for top-loaders and front-loaders
  – Top-loader standards have two phases
- Front-loaders: 43% energy savings and
- Top-loaders: 26% energy savings and 16% water savings (2015), 37% energy savings and 37% water savings (2018)

# Clothes Washer Standards

## (MEF/WF)

<table>
<tr><th>Category</th><th>Current Standard</th><th>2015 Standard</th><th>2018 Standard</th></tr>
<tr><td>Top-load, std size</td><td rowspan="2">1.26/9.5</td><td>/8.0</td><td>2.0/6.0</td></tr>
<tr><td>Front-load, Std size</td><td colspan="2">2.2/4.5</td></tr>
<tr><td>Top-load, Compact 1.72</td><td>0.65/18.4</td><td>1.26/14.0</td><td>1.81/11.6</td></tr>
<tr><td>Front-load, Compact</td><td>N/A</td><td colspan="2">1.72/8.0</td></tr>
</table>

# Clothes Dryer Standards

- 5% energy savings using current test procedure.
- In addition, test procedure modified to address effectiveness of auto termination. This provides significant additional energy savings from reduced over-drying.
- Standard takes effect Jan. 1, 2015

# Room Air Conditioner Standards

(Effective June 1, 2014)

| Product Description | Change in Standard | New Standard (EER) |
|---|---|---|
| ***Without Reverse Cycle w/Louvers*** | | |
| <6,000 | 15% | 11.2 |
| 6,000 to 7,999 | 15% | 11.2 |
| 8,000-13,999 | 12% | 11.0 |
| 14,000 to 19,999 | 11% | 10.8 |
| 20,000-27,999 | 11% | 9.4 |
| ≥28,000 | 6% | 9.0 |
| ***Without Reverse Cycle w/o Louvers*** | | |
| < 6,000 | 13% | 10.2 |
| 6,000 to 7,999 | 13% | 10.2 |
| 8,000-10,999 | 14% | 9.7 |
| 11,000-13,999 | 13% | 9.6 |
| 14,000-19,999 | 11% | 9.4 |
| ≥20,000 | 11% | 9.4 |
| ***With Reverse Cycle*** | | |
| < 20,000 w/Louvers | 10% | 9.9 |
| ≥ 20,000 w/Louvers | 11% | 9.4 |
| < 14,000 w/o Louvers | 11% | 9.4 |
| ≥ 14,000 w/o Louvers | 10% | 8.8 |
| **Casement** | | |
| Casement Only | 10% | 9.6 |
| Casement-Slider | 11% | 10.5 |

# Dishwasher Standards

- Improve efficiency of standard and compact dishwashers.
  - Standard units to 307 kWh/yr, 5.0 gal/cycle
  - Compact units to 222 kWh/yr, 3.5 gal/cycle
- Same as the July 2011 ENERGY STAR specification
- Reduces energy use 14% and water use 23%
- Takes effect Jan. 1, 2013

# Smart Appliances

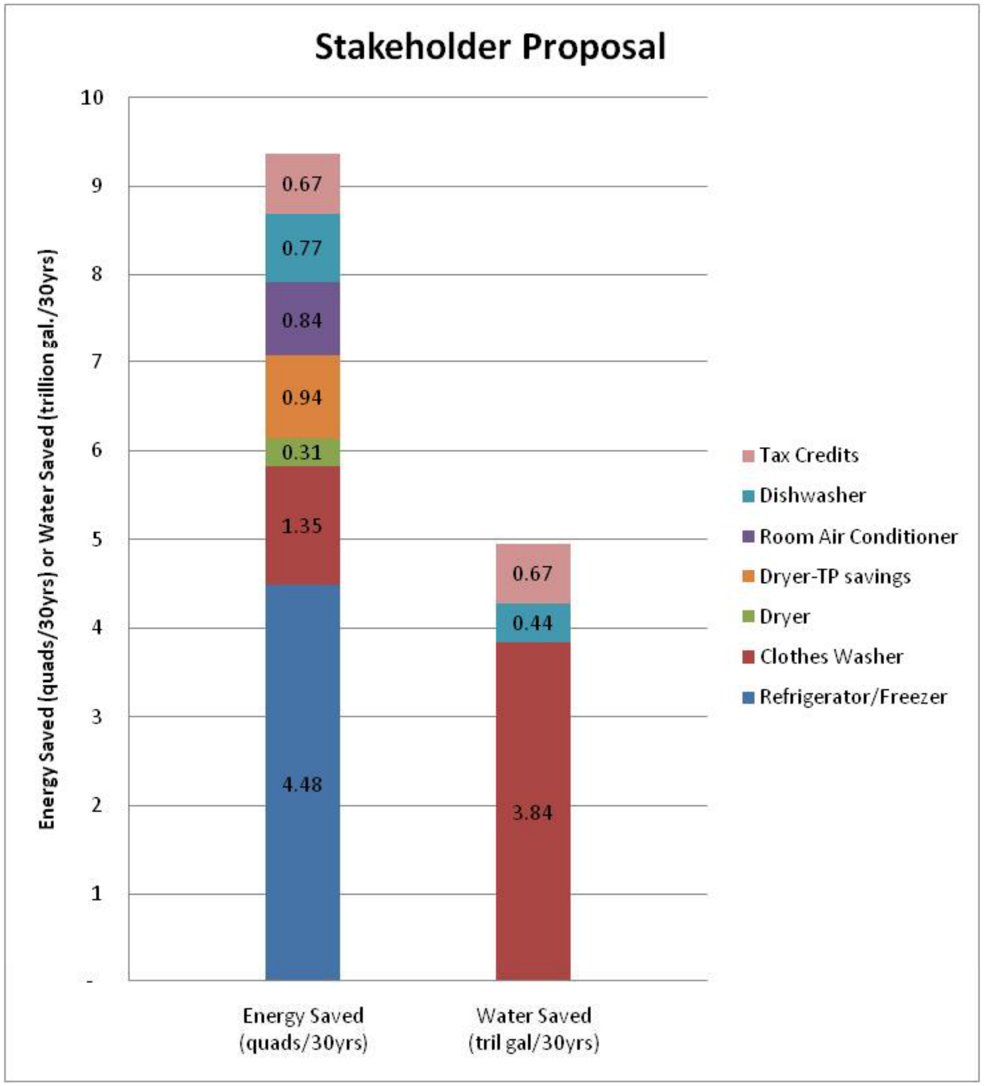
- Parties will jointly petition EPA to provide a

  appliance”.
  - Will include ability to push some energy use to off-peak periods when receive a signal from the utility.
- Parties will also work together to develop a proposal for tax or other incentives for appliances with “smart” capabilities.

# Proposed Tax Incentives
## (extension of current incentives that expire 12/31/10)

| Product | Level | Amount | Year |
|---|---|---|---|
| Clothes washer-Top Load | 2.2 MEF/4.5 WF | $175 | capped in 2011, nothing after 2011 |
| Clothes washer-Top Load | 2.4 MEF/4.2 WF | $200 | uncapped in 2011-2013 |
| Clothes washer-Front and Top Load | 2.8 MEF/3.5 WF | $250 | uncapped in 2011-2013 |
| | | | |
| Refrigerator | 30% better than current standard | $150 | capped in 2011-2013 |
| Refrigerator | 35% better than current standard | $200 | uncapped in 2011-2013 |
| Freezers | 30% (auto deforst) and 25% (manual defrost) better than current standards | $150 | capped in 2011-2012; no incentive 2013 |
| Freezers | 40% (auto deforst) and 35% (manual defrost) better than current standards | $200 | uncapped in 2011-2013 |
| | | | |
| Dishwasher* | 307 kWh/5.0 WF | $25 | capped in 2011, no incentive after 2011 |
| Dishwasher* | 295 kWh/4.25 WF | $50 | capped in 2011-2013 |
| Dishwasher* | 280 kWh/4.0 WF | $75 | uncapped in 2011-2013 |
| * extra 0.5 WF for greater than 12 place settings | | | |

# Energy and Water Savings from Standards



ATTACHMENT 2

**Energy Efficient and Smart Appliance Agreement of 2010**
**Refrigerator/Freezer**

| Product Class | Product Description | January 1, 2014 | | |
|---|---|---|---|---|
| | | Change in Standard | Revised Standard Equation | |
| | | | Slope | Intercept |
| ***Standard size*** | | | | |
| **Automatic Defrost Refrigerator-Freezers** | | | | |
| 3 | Top Freezer w/o TTD ice | 25% | 7.35 | 207.0 |
| 6 | Top Freezer w/ TTD ice | 25% | 7.65 | 267.0 |
| 4 | Side Freezer w/o TTD ice | 25% | 3.68 | 380.6 |
| 7 | Side Freezer w/ TTD ice | 25% | 7.58 | 304.5 |
| 5 | Bottom Freezer w/o TTD ice | 20% | 3.68 | 367.2 |
| 5a/19 | Bottom Freezer w/ TTD ice | 20% | 4.00 | 431.2 |
| **Manual & Partial Automatic Refrigerator-Freezers** | | | | |
| 1 | Manual Defrost | 20% | 7.06 | 198.7 |
| 2 | Partial Automatic | 20% | 7.06 | 198.7 |
| **All Refrigerators** | | | | |
| 1a | Manual Defrost | 20% | 7.06 | 198.7 |
| 3a | Automatic Defrost | 25% | 7.35 | 207.0 |
| **All Freezers** | | | | |
| 8 | Upright with manual defrost | 25% | 5.66 | 193.7 |
| 9 | Upright with automatic defrost | 30% | 8.70 | 228.3 |
| 10 | Chest with manual defrost | 25% | 7.41 | 107.8 |
| 10a/20 | Chest with automatic defrost | 30% | 10.33 | 148.1 |
| ***Compact Size*** | | | | |
| **Automatic Defrost Refrigerator-Freezers** | | | | |
| 13/15 | Top Freezer and Bottom Freezer | 15% | 10.80 | 301.8 |
| 14 | Side Freezer | 20% | 6.08 | 400.8 |
| **Manual & Partial Automatic Refrigerator-Freezers** | | | | |
| 11 | Manual Defrost | 25% | 8.03 | 224.3 |
| 12 | Partial Automatic | 25% | 5.25 | 298.5 |
| **All Refrigerators** | | | | |
| 11a | Manual defrost | 25% | 8.03 | 224.3 |
| 13a | Automatic defrost | 25% | 9.53 | 266.3 |
| **All Freezers** | | | | |
| 16 | Upright with manual defrost | 10% | 8.80 | 225.7 |
| 17 | Upright with automatic defrost | 10% | 10.26 | 351.9 |
| 18 | Chest | 10% | 9.41 | 136.8 |
| ***Built-ins*** | | | | |
| **Automatic Defrost Refrigerator-Freezers** | | | | |
| 3B | Top Freezer w/o TTD ice | 20% | 7.84 | 220.8 |
| 4B | Side Freezer w/o TTD ice | 20% | 3.93 | 406.0 |
| 7B | Side Freezer w/ TTD ice | 20% | 8.08 | 324.8 |
| 5B | Bottom Freezer w/o TTD ice | 15% | 3.91 | 390.2 |
| 5aB | Bottom Freezer w// TTD ice | 15% | 4.25 | 458.2 |
| **All Refrigerators** | | | | |
| 3aB | Automatic Defrost | 20% | 7.84 | 220.8 |
| **All Freezers** | | | | |
| 9B | Upright with automatic defrost | 25% | 9.32 | 244.6 |

**Energy Efficient and Smart Appliance Agreement of 2010**
**Clothes Washers**

| Product Description | New Standard Jan. 1, 2015 | | New Standard Jan. 1, 2018 | |
|---|---|---|---|---|
| | Change in Standard | New Standard (MEF/WF) | Change in Standard | New Standard (MEF/WF) |
| Top-Loading, Compact (less than 1.6 cubic feet capacity) | 48%/24% | 1.26/14.0 | 64%/37% | 1.81/11.6 |
| Top-Loading, Standard | 26%/16% | 1.72/8.0 | 37%/37% | 2.0/6.0 |
| Front-Loading, Standard | 43%/52% | 2.2/4.5 | N/A | N/A |
| Front-Loading, Compact (less than 1.6 cubic feet capacity) | new | 1.72/8.0 | N/A | N/A |

**Energy Efficient and Smart Appliance Agreement of 2010**

**Dryers**

| Product Description | January 1, 2015 | |
|---|---|---|
| | Change in Standard | New Standard (EF) |
| Vented Electric Standard | 5% | 3.17 |
| Vented Electric Compact 120V | 5% | 3.29 |
| Vented Electric Compact 240V | 5% | 3.05 |
| Vented Gas | 5% | 2.81 |
| Vent-less Electric Compact 240V | new | 2.37 |
| Vent-less Electric Combination Washer/Dryer | new | 1.95 |

**Energy Efficient and Smart Appliance Agreement of 2010**
**Room Air Conditioners**

| Product Description | June 1, 2014 | |
|---|---|---|
| | Change in Standard | New Standard (EER) |
| ***Without Reverse Cycle w/Louvers*** | | |
| <6,000 | 15% | 11.2 |
| 6,000 to 7,999 | 15% | 11.2 |
| 8,000-13,999 | 12% | 11.0 |
| 14,000 to 19,999 | 11% | 10.8 |
| 20,000-27,999 | 11% | 9.4 |
| ≥28,000 | 6% | 9.0 |
| ***Without Reverse Cycle w/o Louvers*** | | |
| < 6,000 | 13% | 10.2 |
| 6,000 to 7,999 | 13% | 10.2 |
| 8,000-10,999 | 14% | 9.7 |
| 11,000-13,999 | 13% | 9.6 |
| 14,000-19,999 | 11% | 9.4 |
| ≥20,000 | 11% | 9.4 |
| ***With Reverse Cycle*** | | |
| < 20,000 w/Louvers | 10% | 9.9 |
| ≥ 20,000 w/Louvers | 11% | 9.4 |
| < 14,000 w/o Louvers | 11% | 9.4 |
| ≥ 14,000 w/o Louvers | 10% | 8.8 |
| **Casement** | | |
| Casement Only | 10% | 9.6 |
| Casement-Slider | 11% | 10.5 |

**Energy Efficient and Smart Appliance Agreement of 2010**
**Dishwashers**

| Product Description | January 1, 2013 | |
|---|---|---|
| | Change in Standard | New Standard |
| Standard (≥ 8 place settings plus 6 serving pieces) | 14% & 23% | 307 kWh/year & 5.0 gallons/cycle |
| Compact (< 8 place settings plus 6 serving pieces) | 15% & 24% | 222 kWh/year & 3.5 gallons/cycle |

**<u>Agreement on Minimum Federal Efficiency Standards,</u>**
**<u>Smart Appliances, Federal Incentives and</u>**
**<u>Related Matters for Specified Appliances</u>**

**<u>July 30, 2010</u>**

**THIS AGREEMENT** memorializes the commitments made by the undersigned representatives of the organizations (the "Joint Stakeholders") regarding joint recommendations for new energy and water conservation standards, test procedures, tax incentives and Energy Star criteria for specified major home appliances. The Joint Stakeholders will jointly submit to the United States Congress and the Administration (including, but not limited to the Department of Energy (DOE) and the Environmental Protection Agency (EPA)) this Agreement and the specific recommendations herein in such form as will facilitate their adoption. The Joint Stakeholders agree to pursue a multi-pronged approach designed to achieve Congressional and regulatory implementation of all the elements contained in the agreement. Any changes to this agreement must be mutually agreed to by the joint Stakeholders.

1. The Joint Stakeholders will jointly submit to Congress and, in good faith, proactively seek enactment of the energy and water conservation standards contained in Attachment I. The Joint Stakeholders will submit to Congress recommended amendments to the Energy Policy and Conservation Act enacting these standards (Attachment II). These amendments include revised standards for refrigerator/freezers, clothes washers, clothes dryers, room air conditioners and dishwashers.

2. Not later than August 1, 2010, the Joint Stakeholders shall submit this agreement to DOE. The Joint Stakeholders shall jointly propose that DOE issue final rules adopting each of the energy conservation standards contained in Attachment I and the amendments presented to Congress and will proactively advocate for DOE adoption of these standards. The Joint Stakeholders agree that the recommended standards address all of the statutory criteria that the Department is required to take into account in promulgating new energy and water conservation standards for the affected products with respect to the specified efficiency criteria.

3. For refrigerators/freezers, clothes washers, room air conditioners and clothes dryers, the Joint Stakeholders shall submit comments to each product's DOE docket supporting the recommendations. For refrigerator/freezers, such comment shall be filed not later than August 10, 2010; for clothes dryers and room air conditioners, not later than September 10, 2010 and for clothes washers not later than October 31, 2010. In the case of dishwashers (for which no rulemaking is currently underway) not later than September 15, 2010, the Joint Stakeholders shall petition DOE to initiate a rulemaking and to publish a final rule by September 2011.

4. The Joint Stakeholders have made no agreement concerning the appropriate levels for standby or off mode energy consumption and agree that stakeholders will comment to

DOE as they view appropriate during DOE's rulemaking process for each of the affected products, as applicable.

5. The Joint Stakeholders agree that pending amendments to test procedures for the affected products should be completed by DOE, subject to input from all stakeholders and agree to recommend that DOE translate the standards contained in this agreement to equivalent levels specified under revised test procedures.

6. The Joint Stakeholders agree to jointly petition DOE to initiate a rulemaking by January 1, 2012 to be completed by December 31, 2012 to revise the test procedure for refrigerators/freezers to incorporate measured ice maker energy use. The Joint Stakeholders will make good faith efforts to work collaboratively through AHAM's HRF-1 task force to arrive at a joint test procedure recommendation. AHAM will invite the non-manufacturer signers to this agreement to designate a participant for the task force only for the development of this initial test procedure for refrigerators/freezers to incorporate measured ice maker energy use. As part of the petition to be filed, the Joint Stakeholders further agree to petition DOE for rulemaking to incorporate measured ice maker energy use into an amended refrigerator standard to be completed within six months of a revised test procedure incorporating measured ice maker energy use based on the procedure recommended by AHAM's HRF-1 task force and to recommend that this amended standard take effect three years after a final rule is published. This commitment to petition for rulemaking and standards revisions applies whether a specific consensus test procedure is developed by AHAM's HRF-1 task force or not.

7. The Joint Stakeholders agree to submit the letters and attachments recommending certain modifications to the test procedures for refrigerator/freezers, clothes washers and clothes dryers contained in Attachment III, IV and V not later than August 1, 2010. The Joint Stakeholders agree that each party may advocate for any other modifications to the test procedures, provided such modification is not in direct contradiction to the attached recommendations.

8. The Joint Stakeholders will jointly submit to Congress recommendations for extending the existing federal manufacturer tax credits for specified appliances as described in Attachment VI.

9. The Joint Stakeholders will in good faith jointly develop and proactively support the adoption of federal tax credits or other incentives for widespread deployment and effective integration of smart-grid enabled versions of appliances subject to this agreement across the United States.

10. The Joint Stakeholders will jointly petition EPA and DOE no later than September 30, 2010 to provide a 5% credit to the energy performance level required to meet ENERGY STAR eligibility criteria for smart-grid enabled appliances that are subject to this agreement.

11. Any filings, proposals or responses to DOE notices shall be consistent with this Agreement and the parties shall file rulemaking petitions, file comments or take other actions with respect to DOE or other regulatory agencies consistent with this Agreement.

12. The Joint Stakeholders agree to cooperate with each other in the preparation of press releases and public statements in support of this Agreement.

13. The Joint Stakeholders agree to support and cooperate with each other to obtain passage of the legislation described in the Agreement, including advocacy in Congress and to the Administration. The Joint Stakeholders agree to develop and jointly recommend legislative history concerning the recommended amendments.

14. The Joint Stakeholders agree to consult with and obtain consent from all parties before supporting, advocating or agreeing to changes in the legislation. Such consent will not unreasonably be withheld.

15. The Joint Stakeholders agree not to attempt to overturn or revise, or to file or support any legal or legislative challenge to, the recommendations once adopted, whether by Act of Congress or by rule. The Stakeholders agree to support DOE in a manner as each one deems to be reasonable and appropriate in defending any legal, legislative, or administrative challenge to a final rule that adopts the proposed standards. This provision will still apply if DOE, on its own volition, adopts a rule that includes minor deviations from Attachment I. The Joint Stakeholders agree to consult with respect to their responses to any deviation from the recommendations and to make good faith efforts to respond jointly.

16. The Joint Stakeholders agree to implement the commitments made in this Agreement individually or in groups. Each Joint Stakeholder will respond in good faith to reasonable requests by other Joint Stakeholders for joint implementation of any of these commitments.

17. Any additional mutually agreed to changes to this agreement will be provided to Congress and the Administration as necessitated.

18. Nothing in this Agreement is intended to inhibit in any way efforts by individual stakeholders to research, develop, or market products to standards that differ from those contemplated by this Agreement, provided such products are in compliance with applicable laws and regulations.

19. Nothing in this Agreement is intended to direct any technical or product design approach to achieving efficiency standards and the parties shall not take any act to establish any such common approach.

20. This Agreement is hereby agreed to, in counterparts, by the undersigned Joint Stakeholders. This Agreement binds the undersigned Joint Stakeholders, their

employees, their agents, and any successors and will take effect when all signatures are affixed.  This agreement applies until December 31, 2012, except clause 15 which applies until December 31, 2013.

Joint Stakeholders

Manufacturers

Joseph McGuire
President
Association of Home Appliance Manufacturers

Advocates

Steven Nadel
Executive Director
American Council for an Energy Efficient Economy

*On Behalf of –*

*Members of Major Appliance Division:*
*Whirlpool*
*General Electric*
*Electrolux*
*LG Electronics*
*BSH*
*Alliance Laundry*
*Viking Range*
*Sub-Zero Wolf*
*Friedrich A/C*
*U-Line*
*Samsung*
*Sharp Electronics*
*Miele*
*Heat Controller*
*AGA Marvel*
*Brown Stove*
*Haier*
*Fagor America*
*Airwell Group*
*Arcelik*
*Fisher & Paykel*
*Scotsman Ice*
*Indesit*
*Kuppersbusch*
*Kelon*
*DeLonghi*

*Appliance Standards Awareness Project*
*Natural Resources Defense Council*
*Alliance to Save Energy*
*Alliance for Water Efficiency*
*Northwest Power and Conservation Council*
*Northeast Energy Efficiency Partnerships*
*Consumer Federation of America*
*National Consumer Law Center*

Attachments

(I) Recommended energy and water conservation standards
(II) Recommended legislative amendments
(III) Recommendations concerning refrigerator test procedures
(IV) Recommendations concerning clothes washer test procedures
(V) Recommendations concerning clothes dryer test procedures
(VI) Recommended legislative amendment for tax incentives

# ATTACHMENT B

PNNL-19083

Prepared for the U.S. Department of Energy
under Contract DE AC05 76RL01830

# Use of Residential Smart Appliances for Peak-Load Shifting and Spinning Reserves

## Cost/Benefit Analysis

### REPORT

Chellury (Ram) Sastry
Rob Pratt
Viraj Srivastava
Shun Li

December 2010

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PNNL-19083

# Use of Residential Smart Appliances for Peak-Load Shifting and Spinning Reserves

# Cost/Benefit Analysis

## REPORT

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Viraj Srivastava
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December 2010

Prepared for
the U.S. Department of Energy
under Contract DE-AC05-76RL01830

Pacific Northwest National Laboratory
Richland, Washington 99352

# Abstract

In this report, we present the results of an analytical cost/benefit study of residential “smart appliances”[1] from a utility/grid perspective. This study was prepared as an independent technical analysis of a joint stakeholder[2] petition to the ENERGY STAR program within the Environmental Protection Agency (EPA) and Department of Energy (DOE). The goal of the petition is, in part, to provide appliance manufacturers incentives to hasten the production of smart appliances. The underlying hypothesis is that smart appliances can play a critical role in addressing some of the societal challenges, such as anthropogenic global warming, associated with increased electricity demand, and facilitate increased penetration of renewable sources of power. The appliances we analyzed included refrigerator/freezers, clothes washers, clothes dryers, room air-conditioners, and dishwashers.

The petition requests the recognition that providing an appliance with smart grid capability, i.e., products that meet the definition of a “smart appliance,” is at least equivalent to a corresponding five percent reduction in operational machine efficiencies. It is expected that given sufficient incentives, value propositions, and suitable automation capabilities built into smart appliances, residential consumers will adopt these smart appliances and be willing participants in addressing the aforementioned societal challenges by more effectively managing their home electricity consumption.

The analytical model we used in our cost/benefit analysis consists of a set of user-definable assumptions such as the definition of “on-peak” (hours of day, days of week, months of year), the expected percentage of normal consumer electricity consumption (also referred to as appliance loads) that can be shifted from peak hours to off-peak hours, the average power rating of each appliance, etc. Based on these assumptions, we estimated the wholesale grid operating-cost savings, or “benefits,” that would be realized if the “smart” capabilities of appliances were invoked. The benefits considered were peak-load shifting for some percentage of appliance loads and ancillary services provided by responsive appliance loads. Specifically we considered responsive or dispatchable smart appliance loads meeting power system needs for spinning reserves that would otherwise have to be provided by generators. The rationale for this is that appliance loads can be curtailed for about ten minutes or less in response to a grid contingency without any reduction in the quality of service to the consumer.

We then estimated the wholesale grid operating-cost savings based on historical wholesale-market clearing prices (location marginal and spinning reserve) from major wholesale power markets in the United States. The savings derived from the smart grid capabilities of an appliance were then compared to the savings derived from a five percent increase in traditional operational machine efficiencies, referred to as “cost” in this report, to determine whether the savings in grid operating costs (benefits) are at least as high as or higher than the operational machine efficiency credit (cost).

[1] “Smart Appliances” are capable of either shifting their time of operation or curtailing their operation temporarily upon request. A more detailed definition is presented in Section 1.1.

[2] Stakeholders include Association of Home Appliance Manufacturers (AHAM), American Council for an Energy-Efficient Economy, Natural Resources Defense Council, Consumer Federation of America, and many others.

# Executive Summary

The work reported herein was performed by the Pacific Northwest National Laboratory (PNNL) and funded by the U.S. Department of Energy, Office of Electricity Delivery and Energy Reliability (OE).

In this report, we present the results of our cost/benefit analysis of residential smart appliances. The appliances we consider include refrigerator/freezers (R/F), clothes washers (CW), clothes dryers (CD), room air conditioners (RAC), and dishwashers (DW). By "benefits," we mean the annual savings in the power-grid wholesale operating costs as a result of:

1. smart appliances shifting their operation from on-peak hours to off-peak hours, thereby reducing the need for peak-power producing generators
2. smart appliances being able to temporarily curtail their operation (for up to ten minutes) thereby providing an alternative ancillary service equivalent to spinning reserves in the event of a contingency. Note that request for temporary curtailment can be made at any time during the day on those appliances that are running when a contingency occurs. In this sense smart appliances can be "dispatched" in real-time, and are equivalent to dispatched generators providing spinning reserves[1].

These benefits are estimated based on historical locational marginal prices (LMP) and spinning reserve (SR) prices from various markets in the United States operated and coordinated by well-known Independent System Operators (ISO) and Regional Transmission Operators (RTO) including Pennsylvania-New Jersey-Maryland (PJM) Interconnection, California ISO (CAISO), New York ISO (NYISO), and Electric Reliability Council of Texas (ERCOT).

For the purpose of this report, we define "cost" of an appliance as a percentage "credit" that joint stakeholders are seeking from the EPA to recognize the equivalent or higher benefits that could be achieved through smart grid capabilities as compared to operational efficiencies, as well as to incentivize appliance makers to manufacture smart appliances. The smart appliance credit that is being sought by stakeholders in their joint petition is five percent. In absolute monetary terms, this cost is estimated by applying the five percent credit to each appliance's annual grid operating expenses, which in turn are evaluated based on historical wholesale LMP prices from major markets.

The cost/benefit analysis was undertaken using an analytical model that is a function of a set of input assumptions. These include definitions of on-peak hours, and the days of a week and months of a year those peak hours are expected to occur. They also include annual average electricity consumption by each appliance estimated based on AHAM data and Department of Energy (DOE) standards and test procedures.

In addition to these assumptions, the benefits of each smart appliance depend on how much appliance load is actually available for peak-load shifting and temporary curtailment when in operation to provide

[1] The term "spinning reserve capability" as defined in the joint-stake holder petition is the capability of an appliance to respond to a signal that demands a response intended to temporarily reduce load by a short-term, specified amount, usually 10 minutes. Detailed explanation of what spinning reserves mean and their valuation in wholesale markets is presented in Sections 2.1 and 3.4.3.

the ancillary service equivalent to spinning reserves noted above. First we define what we refer to as *Net Fraction of On-Peak Load Available to Shift*.[2] This is the product of three other fractions:

1. *Fraction of Customers Receiving Grid Signals and Communicating these to an Appliance*, i.e. those consumers who have the capability to receive pricing and other grid signals from a utility or third party energy service providers and passing them on to an appliance to manage its consumption. These signals could be received through a smart meter as part of smart grid advanced metering infrastructure (AMI), or through some other interface into the home. And the signals can either reach the smart appliances directly, or through some intermediary mechanism such as a home gateway or what AHAM refers to as a "hub."[3]

2. Of those customers who have the capability described in #1, some will override, and those remaining will be willing to shift load; these we define as *Fraction of Customers Willing to Shift On-Peak Load*.

3. Finally, among those customers who do not override and are willing to shift peak load as in #2, some may not be willing to shift their entire on-peak load. This is captured through *Fraction of On-Peak Load that Willing Customers Shift*.

Similar to *Net Fraction of On-Peak Load Available to Shift*, we also define *Net Fraction of Load Available to be dispatched for Spinning Reserves* as noted above with the caveat that appliance load is available for dispatch all the time. In other words, any time appliances are operating, they can be interrupted for a short duration, up to 10 minutes or so, by either shutting off completely or reducing their electricity consumption in response to a spinning-reserve request signal (for example, a dryer operating with two heating elements might continue to operate but with only one heating element on). The *Net Fraction of Load Available for Spinning Reserves* is a product of three other fractions:

1. *Fraction of Customers Receiving Grid Signals and Communicating these to an Appliance* as described above.

2. Of those customers who have the capability described in #1, only some of them will be willing to make their appliances available for spinning reserves; these we define as *Fraction of Customers Willing to Provide Spinning Reserves*.

3. Finally, among those customers who do not override a request for spinning reserves as in #2, some may not be willing to make their entire load available for spinning reserves even for a short duration. This is captured through *Fraction of Appliance Load Reduced for Spinning Reserves*.

Finally, an important and key assumption we make in our analysis is what is referred to as "consumer behavior feedback effect". Studies[4] have shown that providing energy-usage feedback to consumers has

---

[2] Appliance load refers to total electricity consumption, and during peak periods all of this load or part of it can be shifted. In the case of refrigerators and freezers, appliance load refers to defrost load or ice-making load, and it is these loads that are available for shifting during peak periods.

[3] Association of Home Appliance Manufacturers (AHAM). 2010. *Assessment of Communication Standards for Smart Appliances: The Home Appliance Industry's Technical Evaluation of Communication Protocols.* Accessed December 9, 2010 at http://www.aham.org/ht/a/GetDocumentAction/i/50696.

[4] American Council for an Energy Efficient Economy. 2010. *Advanced Metering Initiatives and Residential Feedback Programs: A Meta-Review for Household Electricity-Saving Opportunities.* Available at http://www.aceee.org/research-report/e105

resulted in reduced energy consumption. In this work, we hypothesize that through the use of smart appliances, such energy-use feedback mechanisms can further be enhanced. In particular, we assume that an average reduction of 3 – 6 percent per appliance in electricity consumption will be possible due to change in customer behavior as a result of the feedback provided to them through the use of smart appliances.

The smart appliance cost/benefit model we have developed is based on all of the above assumptions, and the End-Use Load and Consumer Assessment Program (ELCAP[5]) load shapes for daily usage patterns. Note that although ELCAP data is based on 1989 appliance consumption ratings, we extrapolate ELCAP data to current energy levels for use in our model. Through ELCAP data, our model estimates the on-peak and off-peak consumption of each appliance. Then, based on these estimates, and on annual hourly average energy market clearing prices (LMP), the annual wholesale production cost in operating a given appliance is evaluated. The savings derived from shifting of a given percentage of peak loads to off-peak periods are also estimated.

When it comes to spinning reserves, our model estimates total appliance load available during on-peak and off-peak periods, taking into account how much load is shifted from peak to off-peak hours. Historical annual hourly spinning-reserve market clearing prices are invoked to value on-peak and off-peak loads serving as sources of spinning reserves.

Finally, the total operational cost savings or “benefits” are those arising from peak-load shifting and spinning reserves. The five percent smart-appliance credit is applied to the total annual operating cost of a given appliance to estimate the monetary value of the credit based on operational machine efficiencies which is the “cost” applied toward making an appliance smart.

In order to get a range of estimates for the benefits and costs, we consider two sets of assumptions: a set of best-case or “optimistic” set of assumptions that lead to highest possible benefits and a set of low-end or “pessimistic” assumptions leading to lower benefits. The optimistic scenario generally assumes that all customers can receive grid signals and communicate these to the appliance and that all customers are willing to shift 100 percent of their on-peak loads, and will make available 100 percent of their load all the time for 10-minute temporary curtailment needed for spinning reserves. The pessimistic scenario generally assumes that 50 percent of customers can receive grid signals and communicate these to the appliance, that 70 percent of customers are willing to shift on-peak loads (90 percent in the case of the 10 minute curtailment needed to for spinning reserves), and that on average these customers will shift about 50 percent of their on-peak load. Furthermore, the optimistic scenario assumes a five-hour peak period on average on all days of a week; the pessimistic scenario uses a four hour peak period on average, and only on weekdays. Finally, under the optimistic scenario, we assume that a 6 percent reduction per appliance in electricity consumption will be possible due to change in customer behavior as a result of the feedback provided to them through the use of smart appliances, and the corresponding reduction under the pessimistic scenario is 3 percent.

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[5] Pratt RG, CC Conner, EE Richman, KG Ritland, WF Sandusky, and ME Taylor. 1989. *Description of Electric Energy Use in Single-Family Residences in the Pacific Northwest*. (End-Use Load and Consumer Assessment Program [ELCAP]). DOE/BP-13795-21, prepared for Bonneville Power Administration by Pacific Northwest Laboratory, Richland, Washington.

Shown in Table 1-1 are the highest possible benefit-to-cost ratios (expressed as percentages) of various appliances based on the "optimistic" set of assumptions.

**Table 1-1**. Benefit-to-Cost Ratios of Smart Appliances Based on "Optimistic" Assumptions

| | DW | CW | RAC | Freezer | Refrigerator | Dryer |
|---|---|---|---|---|---|---|
| **PJM 2006** | 528% | 563% | 733% | 539% | 536% | 680% |
| **ERCOT 2008** | 817% | 871% | 1060% | 881% | 877% | 1054% |
| **NYISO 2008** | 367% | 403% | 585% | 357% | 355% | 462% |
| **NYISO 2006** | 353% | 389% | 712% | 346% | 344% | 442% |
| **CAISO 2008** | 319% | 356% | 554% | 313% | 312% | 396% |

Shown in Table 1-2 are the low-end benefit-to-cost ratios of various appliances based on "pessimistic" set of assumptions.

**Table 1-2**. Benefit-to-Cost Ratios of Smart Appliances Based on "Pessimistic" Assumptions

| | DW | CW | RAC | Freezer | Refrigerator | Dryer |
|---|---|---|---|---|---|---|
| **PJM 2006** | 136% | 134% | 131% | 150% | 150% | 207% |
| **ERCOT 2008** | 203% | 200% | 295% | 230% | 228% | 337% |
| **NYISO 2008** | 107% | 106% | 139% | 112% | 111% | 147% |
| **NYISO 2006** | 112% | 112% | 160% | 119% | 118% | 160% |
| **CAISO 2008** | 99% | 100% | 135% | 102% | 101% | 134% |

Based on more detailed results presented in Section 4.0, it can be easily shown that in the optimistic scenario, spinning reserves account for an average of 46 percent of the total benefits shown in Table 1-1, 32 percent of the total benefits from peak-load shifting, and 22% from the feedback effect. In the pessimistic scenario, as shown in Table 1-2, overall benefits decline, with a higher share of benefits attributable to spinning reserves (average of 50%) and feedback (average of 39%), and a lower share from peak-load shifting (average of 10%). This is the case because one of the key differences between the optimistic and pessimistic scenarios is the larger percentage of appliance loads available for peak-load shifting in the optimistic scenario. However, we do observe from Table 1-1 and Table 1-2, that for all appliances, and for both the optimistic and pessimistic assumption scenarios, the benefit-to-cost ratios either exceed or are close to100 percent in all the markets examined. This means that the annual benefits from having smart grid capabilities in an appliance are greater than an equivalent five percent increase in operational machine efficiencies. The expectation from the petition stake holders then is that if ENERGY STAR adopts this proposal for a five percent incentive for smart appliances, it could facilitate the growth of the smart-appliance industry.

A major extension of this work would be to translate benefits that were evaluated in terms of savings in wholesale power production costs to savings in retail costs and the resulting benefits to rate paying customers. Since the utilities' operating and capital costs are reduced to the extent that smart appliances displace peak load capacity and spinning reserves, their need to recover these costs through retail rates is similarly reduced. In the case of regulated utilities, they periodically appear before a state's public utility commission to make the case for their rates by documenting their costs and defining retail rates to recover them. For unregulated public utilities, this same process is applied, albeit less formally, in setting retail rates. Hence, retail rates should be lower than they would be without the smart appliances, since they lower operating and capital costs at the wholesale level. It behooves the regulators (public utility commissions or governing boards) to ensure that appropriate credit for the cost reductions provided by smart appliances goes toward calculation of the rates of residential customers.

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# Acronyms and Abbreviations

| | |
|---|---|
| AHAM | Association of Home Appliance Manufacturers |
| AMI | advanced metering infrastructure |
| CAISO | California Independent System Operator |
| CD | clothes dryer |
| CW | clothes washer |
| DOE | Department of Energy |
| DR | demand response |
| EF | energy factor |
| ELCAP | End-Use Load and Consumer Assessment Program |
| EIA | Energy Information Administration |
| EPA | Environmental Protection Agency |
| EPRI | Electric Power Research Institute |
| ERCOT | Electricity Reliability Council of Texas |
| FERC | Federal Energy Reliability Commission |
| ISO | independent system operator |
| LMP | locational marginal pricing |
| NERC | North American Electric Reliability Corporation |
| NYISO | New York Independent System Operator |
| PJM | Pennsylvania-New Jersey-Maryland Interconnection |
| RAC | room air conditioner |
| RTO | regional transmission operator |
| SR | spinning reserves |

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# 1.0 Introduction

In its 2010 Annual Energy Outlook, the Energy Information Administration (EIA) projects that electricity use will increase by more than 30 percent by 2035 (EIA 2010). Furthermore, it is noted that increases in electricity demand during peak periods are even more pronounced. In particular, EIA estimates that residential electricity use will increase by 23 percent from 2010-2035 due to various demographic and economic factors. As shown in Figure 1.1 below, estimates in the fall of 2010 were that the residential sector represents around 37 percent of electricity use and was the largest consuming sector of electricity.

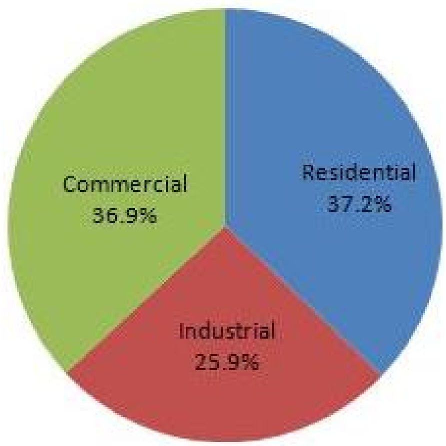


**Figure 1.1**. 2010 Electricity Consumption by Sector (Source: EIA)

It is therefore clear that the residential sector, the focus of this report, is critically important to managing this trend toward greater electricity demand.

## 1.1 Smart Grid, Smart Appliances, and Increased Electricity Demand

Increased use of energy efficiency measures is one well-known approach to managing increased electricity demand. At the same time, it is also very well established today that the smart grid can play a crucial role alongside and in addition to energy efficiency measures in managing increased electricity demand. For example, in his press release of August 31, 2010, DOE secretary Steven Chu quotes an Electric Power Research Institute (EPRI) study which estimates that the implementation of smart grid technologies could reduce electricity use by more than four percent annually by 2030 (DOE 2010b).

A key smart grid application that is crucial to managing electricity consumption is the notion of demand response (DR).[1] DR in the residential sector is currently limited to smart thermostats, i.e., intelligent control of indoor climate by striking a compromise between residents' comfort and energy use. In order to meet the challenges of greater electricity demand in the residential sector, this notion of DR is being extended to smart appliances to let consumers manage their energy use better. For the

[1] There are many formal definitions of DR. In general, DR involves a temporary change in electricity use from normal patterns in response to changing electricity prices or other incentives designed to induce such a change during periods of peak consumption or when power grid stability and reliability are threatened.

purpose of this report, a "smart appliance" is defined[2] as follows:

> **The term "smart appliance"** means a product that uses electricity for its main power source which has the capability to receive, interpret and act on a signal received from a utility, third party energy service provider or home energy management device, and automatically adjust its operation depending on both the signal's contents and settings from the consumer. The product will be sold with this capability, which can be built-in or added through an external device that easily connects to the appliance. The costs of such devices shall be included in the product purchase price.[3]
>
> These signals must include (but are not limited to) appliance delay load, time-based pricing and notifications for load-shedding to meet spinning reserve requirements. Any appliance operation settings or modes shall be easy for an average, non-technical consumer to activate or implement. Additionally, a smart appliance or added device may or may not have the capability to provide alerts and information to consumers via either visual or audible means. The appliance may not be shipped with pre-set time duration limits that are less than those listed below, but may allow consumer-set time duration limits on smart operating modes, and will also allow consumers to override any specific mode (e.g. override a delay to allow immediate operation, limit delays to no more than a certain number of hours, or maintain a set room temperature).

Furthermore, as per the petitioners, smart appliance must have the following attributes:

> **The term "delay load capability**" refers to the capability of an appliance to respond to a signal that demands a response intended to meet peak load deferral requirements, but which also could be used to respond to a sudden maintenance issue at another time of day.
>
> **The term "spinning reserve capability"** means the capability of an appliance to respond to a signal that demands a response intended to temporarily reduce load by a short-term, specified amount, usually 10 minutes. (smart appliances and spinning reserves is taken up in the next section).

In the near future, when smart appliances, along with other smart grid infrastructure (advanced metering infrastructure (AMI), availability of low-cost embedded computing hardware, along with two-way secure communication networks across utility service territories and within customer premises, etc.) are all deployed and appropriate business models and customer incentive structures are in place, the following scenario will be commonplace: when an electric utility company or third-party energy service provider needs to curtail demand, an appropriate signal can be sent to smart appliances at a customer's home, and the appliances are then automated based on customer's preferences to react by possibly reducing load during this critical time period. Such a reduction can be accomplished by either "shifting" usage to a non-critical time of the day as notified so through another signal, or the smart appliance can "shed" load temporarily thereby reducing peak power usage. According the Federal Energy Regulatory

---

[2] This definition of a smart appliance has been proposed by the joint stakeholders in their petition to the EPA. The petition also includes specific definitions by product.

[3] If additional requirements are needed to activate the product's "smart" capabilities as purchased, then prominent labels and instructions must be displayed at the point of purchase and in product literature on what specifically consumers or utilities need to do to achieve these capabilities (e.g. "This product requires snapping in the compatible network module and utility installation of a smart meter or other device for use of capabilities that earned the ENERGY STAR label").

Commission (FERC), the largest gains in reducing peak demand are through full DR participation in the residential sector as shown in Figure 1.2 below.

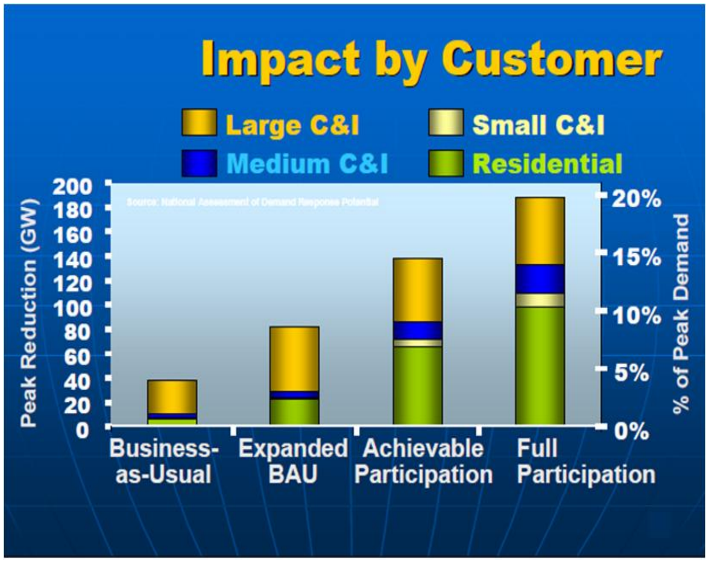


**Figure 1.2**. FERC's Assessment of DR Potential (FERC 2009)

## 1.2 Smart Grid, Smart Appliances, and Increased Penetration of Renewables

In recent years, due to environmental concerns, there have been increasing efforts around the world to incorporate large amounts of renewable sources of energy, such as solar and wind, and diminish the reliance on fossil fuels to create a more diversified energy supply portfolio. For example, DOE has initiated a collaborative effort to explore the possibility of wind power supplying 20 percent of US electricity needs by the year 2030 (DOE 2010c).

One of the key challenges involved with solar and wind as sources of energy is that they are intermittent and cannot be relied upon with certainty. Solar energy output can drop very quickly with passing clouds, while wind energy output changes very frequently, almost every hour. As a result, in order to balance supply and demand, a key objective of power system operation, it is necessary to maintain energy reserves based on conventional generation sources such as natural gas. But doing so defeats the very purpose of incorporating solar and wind energy, namely, decreasing reliance on fossil fuels.

Just as DR through smart appliances is being considered for managing peak electricity demand, considerable efforts have been undertaken to demonstrate the enormous potential of smart appliances (Eto et al. 2007, Kirby and Kueck 2003, Kirby 2003, Kueck et al 2008) to provide crucial reserves that are required to balance supply and demand to support reliable power system operation; this is even more the case with increased penetration of renewables as noted above. Smart appliances are particularly well suited for a class of reserves referred to as “spinning reserves,”[4] because the operation of spinning reserves can be interrupted for short periods in response to a curtailment request without causing any reduction in the quality of service to consumers. Thus, instead of ramping generators up and down to provide reserves for balancing services, smart appliances can manage demand to serve the same purpose. Furthermore, end-use loads can often be curtailed almost instantaneously, in contrast with generators, which must ramp up and down subject to operating constraints in order to avoid equipment damage. Finally, given the potentially large number of responsive end loads, their aggregate response could be extremely reliable when called upon to provide reserves.  Thus, smart appliances could eliminate the need for maintaining fossil-fuel based generation for providing reserves, thereby reducing operating costs and also lowering emissions.

In this work, we undertake a cost/benefit analysis of residential smart appliances from a utility/grid perspective in support of a joint stakeholder petition to the Environmental Protection Agency (EPA) and Department of Energy (DOE).  Specifically, we evaluate what the savings in grid operating costs would be if smart appliances deferred their operation from hours of peak operation to off-peak hours, and also served as replacements for spinning reserves.  The goal of the petition is to provide appliance manufacturers a financial incentive to hasten the production of smart appliances.  The appliances we consider include refrigerator/freezers, clothes washers, clothes dryers, room air conditioners, and dishwashers.  Specifically, the petition calls for a five percent credit to the current energy performance level required to meet ENERGY STAR eligibility criteria for products that meet the definition of a smart appliance.

In Section 2.0, we present a general discussion of power system balancing requirements with special emphasis on spinning reserves.  Then in Section 3.0, we present our cost/benefit analysis methodology (model), including discussions on the assumptions we make and the use of historical market prices in our analysis.  Based on this model, we present benefit-to-cost ratios of various smart appliances in Section 4.0, and finally Section 5.0 summarizes our conclusions.

[4] Spinning reserves are part of what are referred to as contingency reserves that are invoked in response to a sudden disturbance such as failure of a generator or transmission line causing a temporary imbalance between supply and demand. A formal description of spinning reserves is given in Section 2.0.

# 2.0 Power System Reserve Requirements

One of the key requirements that must be addressed by power system operators in order to sustain reliable operations is the need to maintain a continuous balance between generation and load at all times. Balancing generation and load instantaneously and continuously is challenging because loads and generators are constantly fluctuating, both predictably and unpredictably. As was alluded to in Section 1.2, variability of generation is especially acute with integration of large amounts of intermittent renewable sources such as wind and solar. Minute-to-minute load variability is caused by the random turning on and off of millions of individual loads. Longer-term variability arises from predictable factors such as the daily and seasonal patterns of load and weather. Unpredictable variability results from a sudden loss of generators or other equipment, loss of a transmission line, etc. Balancing services in a power system that help overcome these fluctuations and maintain supply/demand balance are referred to as "ancillary services."

There are many types of ancillary services, distinguished from each other based on the time frames over which they are invoked and deployed. The North American Electricity Reliability Corporation (NERC) sets forth standards and rules that power producers are expected to follow regarding the deployment of ancillary services. For example, services needed to correct for fluctuations in the minute-to-minute system load and generator output are referred to as "regulation" and "load following" services (NERC 2002). Over and above these, balancing services over longer time frames include spinning reserves, which are a subset of what are referred to as "contingency reserves" needed to compensate for the worst credible disturbance (WECC 2006). Since our focus in this report is on utilizing smart appliances in place of generators for providing spinning reserves, a brief discussion of spinning reserves is presented next.

## 2.1 Spinning Reserves

To continuously balance supply and demand despite sudden, unexpected failures of generators and/or transmission lines, utilities are expected to maintain what are referred to as contingency reserves to compensate for such failures and restore the generation and load balance in the aftermath of a disturbance or contingency. Typically, the amount of contingency reserves that are maintained is equal to the size of the largest credible disturbance that could occur. For example, the Electric Reliability Council of Texas (ERCOT) maintains enough contingency to guard against the simultaneous loss of two nuclear units.

Contingency reserves further consist of spinning reserves, non-spinning reserves, and replacement reserves. The distinguishing features among these contingency reserve constituents are the time scales over which they are required to be deployed. Spinning reserves are those that can be activated quickly in response to a contingency signal from an ISO/RTO, while non-spinning reserves respond to slower changes. Spinning reserves are typically provided by generators supplying base-load power by operating them below their rated capacity, and then ramping them up when called upon by an ISO/RTO to actually release that unused capacity. In other words, spinning reserves are supplied through unused capacity synchronized with the grid; for this reason, spinning reserves are also called synchronized reserves. Non-spinning reserves are inactive generators that can start up within a short period of time. After a certain period over which spinning and non-spinning reserves are deployed, replacement reserves or other generators (selected based on market bids) are deployed; eventually all the reserves are restored back their pre-contingency levels.

NERC and the Western Electricity Coordinating Council (WECC) have set forth rules on the amount of contingency reserves that power producers must maintain, and the duration over which they must be deployed should they be called upon by an ISO/RTO in the event of a contingency. The exact proportion of spinning, non-spinning, and replacement reserves, and the durations over which they are deployed, vary from region to region and market to market, but they all operate under the following general rules (NERC 2005, WECC 2006):

1. Spinning reserves must be deployed within 10 minutes after receiving a notification signal from an ISO/RTO. Once deployed, the local grid conditions, such as system frequency, must be restored to pre-contingency values within 15 minutes, referred to as the disturbance recovery period.
2. Following an event or disturbance requiring the activation of contingency reserves, all the contingency reserves must be restored to their pre-contingency levels within 105 minutes (NERC rules) or 75 minutes (WECC rules); this includes a 15-minute disturbance recovery period, plus 90 minutes (NERC) or 60 minutes (WECC).

When called upon, spinning reserves, non-spinning reserves, and replacement reserves operate in coordinated fashion as shown below in Figure 2.1.

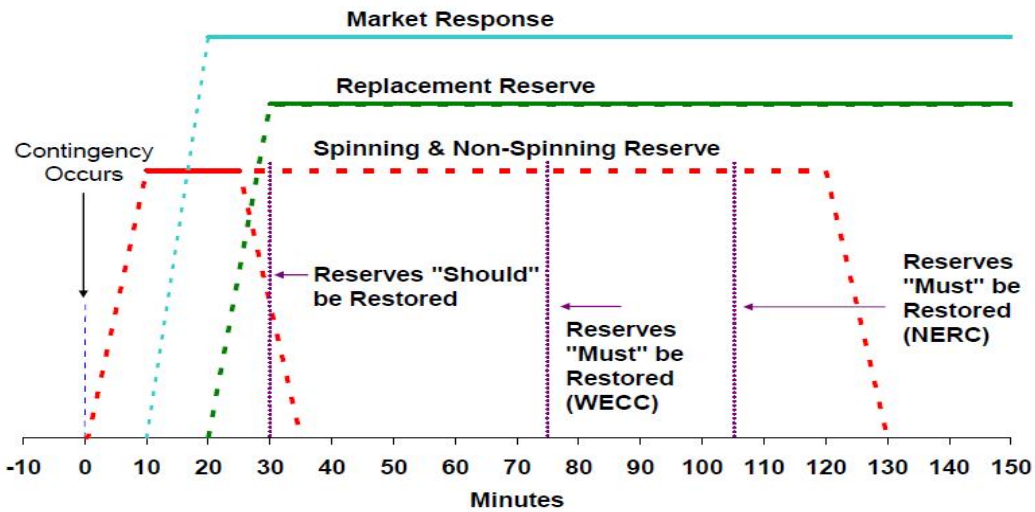


**Figure 2.1**. Deployment of Contingency Reserves in Response to Sudden Loss of Generator or Transmission Line (Source: Kueck et al 2008)

## 2.2 Smart Appliances as Sources of Spinning Reserves

In the previous section, we alluded to the fact that limits on deployment duration of spinning reserves vary from region to region and market to market. Historical data from three major ISOs indicate that spinning reserves are deployed most often for about 10 minutes or less (Eto et al. 2007). In fact, ISOs/RTOs usually would like to restore contingency reserves as quickly as possible, well before the 105-minute limit set by NERC or the 75-minute limit set by WECC, and actual reserve deployment for long durations is extremely rare as shown in Figure 2.2 below.

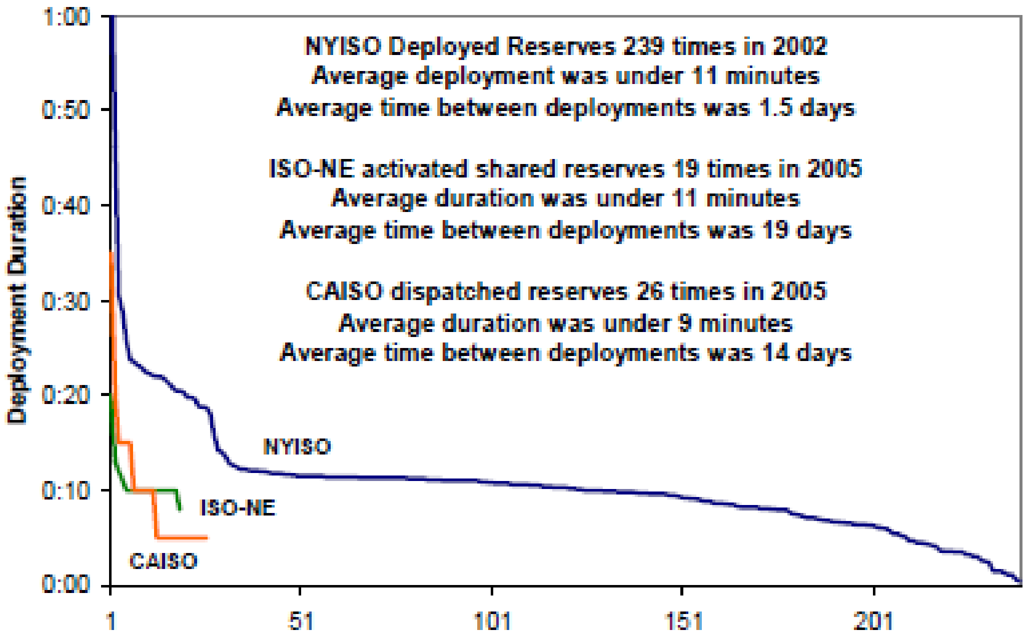


**Figure 2.2**. Number of Reserve Deployments versus their Duration. (Source: Kueck et al 2008)

In lieu of the extremely short deployment duration of spinning reserves, it has been postulated (ORNL/TM-2003/99) that instead of generators supplying spinning reserves, residential loads deployed in the form of smart appliances (see definition of smart appliance given in Section 1.1) serve as sources of spinning reserves; The rationale is that their operation can be interrupted for short periods (up to 10 minutes) in response to a signal from a utility or third-party energy service provider without causing any reduction in the quality of service for consumers. Furthermore, appliance loads can often be curtailed almost instantaneously, in contrast with generators, which must restart, ramp up and down subject to operating constraints in order to avoid equipment damage. Moreover increased emissions can result due to the inefficiencies inherent in restarting and ramping up generation (Wellinghoff et al. 2008). Finally, given the potentially large number of residential loads that are available in any service territory, their aggregate response could be extremely reliable when called upon to provide spinning reserves.

Thus, residential loads deployed in the form of smart appliances could eliminate the need for maintaining some fossil-fuel based generation for providing spinning reserves, thereby reducing operating costs and also lowering emissions. There is also an extensive body of work that demonstrates this potential of smart appliances as sources of spinning reserves (Eto et al 2007, Kirby and Kueck 2003, Kueck et al 2008).

We caution that in the overall context of the rules governing contingency reserve deployment (NERC 2005, WECC 2006); smart appliances are not the exact equivalent of generators providing spinning reserves. This is because after the deployment of spinning reserves for a short duration, up to 10 minutes, non-spinning reserves followed by replacement reserves need to be deployed. Typically, generators set aside for non-spinning reserves are scheduled and synchronized to the power grid once spinning reserves are deployed. It may or may not be practical for residential loads to supply non-spinning reserves as well. Reason being that load curtailment duration has to be well over 10 minutes to cover non-spinning reserves also, and this may not be acceptable to consumers. Thus, if residential loads were to be made the exact equivalent of generators as sources of spinning reserves, then after the 10-minute deployment window, there must some kind of a seamless handover to generators supplying non-spinning reserves. There must be strict market rules that govern this handover.

# 3.0 Smart Appliance Cost/Benefit Analysis Model

In this section we present our smart-appliance cost/benefit model that will be used in later sections to calculate the costs and benefits for each appliance. First, in Section 3.1, we present key user-definable assumptions and appliance data that would be required for the analysis. We present both the "optimistic" and "pessimistic" sets of assumptions leading to best-case and low-end benefits respectively. In Section 3.2, we present historical wholesale market prices that we would utilize to estimate costs and benefits. Then in Section 3.3, we present appliance load shapes, i.e., electricity consumption of each appliance over each hour of an average day, and finally in Section 3.4, we present the methodology we use to estimate costs and benefits of smart appliances.

## 3.1 Assumptions

In this section, we present the set of input assumptions and other raw data on which calculations of the benefits and costs are based.

### 3.1.1 On-Peak Hours

A key input to our analysis framework is the notion of "on-peak" hours on any day. These are those hours when consumption for electricity peaks relative to that during the rest of the day. Shown in Table 3-1 and Table 3-2 are optimistic and pessimistic definitions of on-peak hours, respectively, for all appliances except RACs. Note the difference. In the optimistic view, on-peak hours start at noon and continue through hour 17 (i.e., until 6 p.m.), and they occur on all days of a week. In the pessimistic view, on-peak hours start at 1 p.m. and continue through hour 17, and they occur only on weekdays.

**Table 3-1**. On-Peak, Off-Peak, and Hours to Which the Load is Shifted[1] for all Appliances except RACs – Optimistic View

| | On-Peak Defintion | | | Shift Load To Hours | |
|---|---|---|---|---|---|
| | Hour | Months | Weekday (Mon=1) | | |
| **Start At** | 12 | 1 | 1 | 18 | 0 |
| **Through** | 17 | 12 | 7 | 23 | 11 |

[1] The "Shift Load To Hours" lets user specify which hours are off-peak, i.e., the hours to which peak load can be shifted; they need not be all of the non on-peak hours, only some sub set of them (In Table 3-1 and Table 3-2, they happen to be the same as all of the non on-peak hours).

**Table 3-2**. On-Peak, Off-Peak, and Hours to Which the Load is Shifted for all Appliances except RACs – Pessimistic View

| | On-Peak Defintion | | | Shift Load To Hours | |
|---|---|---|---|---|---|
| | Hour | Months | Weekday (Mon=1) | | |
| Start At | 13 | 1 | 1 | 17 | 0 |
| Through | 16 | 12 | 5 | 23 | 12 |

In Table 3-1 and Table 3-2, the two "Shift Load To Hours" columns allow for the possibility that "shift-to" hours can cross midnight: for example, in Table 3-1, peak load is shifted to run anywhere between hour18 and midnight, or from midnight up to 11 a.m. the next day.

RAC consumption occurs only during the summer months, and in all other months, there is no RAC consumption. Table 3-3 and Table 3-4 are optimistic and pessimistic definitions of on-peak hours for RACs. Note that in both cases, on-peak hours for RACs occur only during the months June through September.

**Table 3-3**. On-Peak, Off-Peak, and Hours to Which the Load is Shifted for RACs - Optimistic View

| | On-Peak Defintion | | | Shift Load To Hours | |
|---|---|---|---|---|---|
| | Hour | Months | Weekday (Mon=1) | | |
| Start At | 12 | 6 | 1 | 18 | 0 |
| Through | 17 | 9 | 7 | 23 | 11 |

**Table 3-4**. On-Peak, Off-Peak, and Hours to Which the Load is Shifted for RACs - Pessimistic View

| | On-Peak Defintion | | | Shift Load To Hours | |
|---|---|---|---|---|---|
| | Hour | Months | Weekday (Mon=1) | | |
| Start At | 13 | 6 | 1 | 17 | 0 |
| Through | 16 | 9 | 5 | 23 | 12 |

Given months (Months/Year) and days of week (Days/Week) during which on-peak hours occur as shown in Table 3-1 through Table 3-4, the numbers of days in the year during which those on-peak hours occur, Days/Year, can be calculated as follows:

$$\text{Days/Year} = [365 * (\text{Months/Year}) / 12] * [(\text{Days/Week}) / 7]$$

### 3.1.2 Annual Electricity Consumption

Annual electricity consumption, presented below for each appliance, is another key data input to our cost/benefit analysis model. This data was provided to us by AHAM (AHAM 2009), and is also based on DOE appliances & commercial equipment standards (DOE 2010a).

#### 3.1.2.1 Annual Electricity Consumption: Clothes Dryer (CD)

The annual CD electricity consumption data is presented below:

Energy factor (EF) for standard electric CD = 3.01 lbs/kWh/cycle

DOE standard sized CD load = 7 lbs

CD electricity consumption per cycle = DOE standard sized dryer load (7 lbs) ÷
EF (3.01 lbs/kWh/cycles) = 2.33 kWh/cycle

CD cycles/year (latest DOE proposal[2]) = 283 cycles/year

CD electricity consumption/year = 2.33 kWh/cycle * 283 cycles/year = 658 kWh/year

#### 3.1.2.2 Annual Electricity Consumption: Room Air Conditioner (RAC)

RAC electricity consumption data below is presented below:

RAC annual usage = 750 hours

RAC electricity consumption /year = 693 kWh/year

#### 3.1.2.3 Annual Electricity Consumption: Freezer

Freezer electricity consumption data is presented below:

Freezer electricity consumption /year = 423 kWh/year

#### 3.1.2.4 Annual Electricity Consumption: Refrigerator

The refrigerator electricity consumption data is presented below:

There are three main factors that contribute to a refrigerator's annual electricity consumption: the first is the consumption needed to keep refrigerator's contents at a certain temperature; the second is the electricity required for making ice. And finally, the electricity consumed for periodic defrosting. We present all three parts below.

Total refrigerator electricity consumption /year= 450 kWh/year

Average coefficient of performance (COP) of compressor = 1.5

[2] Current DOE standard = 416 cycles/year

| | | |
|---|---|---|
| Heat electricity consumption for defrost/day | = 500 W for 10 minutes per day | = 0.083 kWh/day |
| Post-defrost cool-down electricity consumption/day[3] | = 0.083 kWh/day ÷ COP | = 0.05 kWh/day |
| Electricity consumption for defrost/year | = (0.083 + 0.05) kWh/day * 365 days/year | = 50.7 kWh/year[4] |
| Ice-making electricity consumption/day | = 0.23 kWh/day (at 1.8 lbs of ice/day) | |
| Ice-making electricity consumption/year | = 0.23 kWh/day * 365 days/year | = 84 kWh/year[5] |

### 3.1.2.5 Annual Electricity Consumption: Clothes Washer (CW)

CWs present some unique challenges for the following reasons. CWs use hot water from the residence water heater during the wash cycle. So, the first issue is that overall electricity consumption by a CW must be split between CW machine consumption, and CW water-heater consumption. Furthermore, not all residential water heaters use electricity for their operation — many residential water heaters are gas-fired. Both these issues are taken into account in estimating CW electricity consumption.

| | | | | |
|---|---|---|---|---|
| Energy consumption per CW cycle | = | 0.71 kWh/cycle | | |
| CW cycles/year (latest DOE proposal[6]) | = | 295 Cycles/year | | |
| CW energy consumption /year | = | 0.71 kWh/cycle * 295 cycles/year | = | 209 kWh/year |
| CW machine energy (electricity) consumption /year | = | 50% of CW energy consumption /year[7] | = | 105 kWh/year |
| CW hot water energy (electricity + gas) consumption /year | = | 50% of CW energy consumption /year | = | 105 kWh/year |

In order to estimate percentage of CWs that are supplied from gas-fired water heaters, we use data from DOE (EERE 2009).

| | | | | |
|---|---|---|---|---|
| Total residential energy consumption for water heating | = | 1.67 Quadrillion Btu | | |
| Total electricity consumption for residential water heating | = | 0.42 Quadrillion Btu | | |
| Residential water-heating electricity usage fraction | = | 0.42 ÷ 1.67 | = | 25% |

---

[3] After defrost, compressor must run longer. If 10 BTU of heat is added as a result of defrost, then compressor needs to consume electricity to remove those 10 BTUs.
[4] Defrost energy consumption of 50.7 kWh/year amounts to 11% of 450 kWh/year (total annual refrigerator energy consumption/year).
[5] Ice-making energy consumption of 84 kWh/year amounts to 18.7% of 450 kWh/year (total annual refrigerator energy consumption/year).
[6] Current DOE standard = 392 cycles/year
[7] The split of total CW annual energy use between machine use and hot water energy use was supplied by AHAM.

| | | | | | | |
|---|---|---|---|---|---|---|
| CW hot-water electricity consumption /year | = | 25% of CW hot-water energy (electricity + gas) consumption /year | = | 25 % of 139 kWh/year | = | 34.75 kWh/year |

#### 3.1.2.6 Annual Electricity Consumption: Dishwasher (DW)

The dishwasher electricity consumption data presented below is split between usage by the dishwasher and water heating as was done for CWs above:

| | | | | |
|---|---|---|---|---|
| Energy consumption per DW cycle | = | 1.45 kWh/cycle | | |
| DW cycles/year | = | 215 Cycles/year | | |
| DW energy consumption /year | = | 1.45 kWh/cycle * 215 cycles/year | = | 312 kWh/year |
| DW machine energy (electricity) consumption /year | = | 50% of DW energy consumption /year | = | 156 kWh/year |
| CW hot water energy (electricity + gas) consumption /year | = | 50% of CW energy consumption /year | = | 156 kWh/year |

Finally,

| | | | | | | |
|---|---|---|---|---|---|---|
| DW hot-water electricity consumption /year | = | 25% of DW hot-water energy (electricity + gas) consumption /year | = | 25 % of 156 kWh/year | = | 39 kWh/year |

### 3.1.3 Peak Load-Shift Fraction

The benefits of each smart appliance depend on how much appliance load is actually available for peak-load shifting. “Appliance load” refers to total electricity consumption, and during peak periods all of this load or part of it can be shifted. In the case of refrigerators/freezers, appliance load refers to defrost load or ice-making load, and it is these loads that are available for shifting during peak periods. In the case of CWs and DWs, we have machine-only consumption, and water-heater consumption. Recall, CWs and DWs use hot water from installed residential water heaters for their operation. And furthermore, not all residential water heaters are electricity powered, many are gas-fired (see Sections 3.1.2.5 and 3.1.2.6). We consider all these splits in estimating the CW and DW electricity load available for shifting away from peak hours.

Peak load-shift fraction determines the amount of appliance load that is shifted from peak hours to "shift-to" hours. (Recall the definition of on-peak and "shift to" hours described in Section 3.1.1). Formally, we refer to this fraction as *Net Fraction of On-Peak Load Available to Shift*. This is the product of three other fractions:

1. *Fraction of Customers Receiving Grid Signals and Communicating These to an Appliance*, i.e. those consumers who have the capability to receive pricing and other grid signals from a utility or third-party energy service providers and passing them on to an appliance to manage its consumption. These signals could be received through a smart meter as part of smart grid advanced metering infrastructure (AMI), or through some other interface into the home. And the signals can reach the smart appliances either directly or through some intermediary mechanism such as a home gateway or what AHAM refers to as a "hub" (AHAM 2010).

2. Of those customers who have the capability described in #1, some will override, and the remaining will be willing to shift load; these we define as *Fraction of Customers Willing to Shift On-Peak Load*.

3. Finally, among those customers who do not override and are willing to shift peak load as in #2, some may not be willing to shift their entire on-peak load. This is captured through *Fraction of On-Peak Load that Willing Customers Shift*.

Shown in Table 3-5 are the various best-case "optimistic" and worst-case "pessimistic" assumptions for the above three fractions for all appliances except refrigerators and freezers. Also shown is the best-case and worst-case *Net Fraction of On-Peak Load Available to Shift* computed based on these fractions.

In the case of freezers and refrigerators, the on-peak loads are split into their defrost and ice-making components as shown in Table 3-6.

**Table 3-5**. Net Fraction (Percentage) of On-Peak Load Available to Shift for all Appliances Except Freezers and Refrigerators

| | Fraction of Customers Receiving Grid Signals and Communicating These to an Appliance | | Fraction of Customers Willing to Shift On-Peak Load | | Fraction of On-Peak Load that Willing Customers Shift | | Net Fraction of On-Peak Load Available to Shift | |
|---|---|---|---|---|---|---|---|---|
| Appliance | Optimistic | Pessimistic | Optimistic | Pessimistic | Optimistic | Pessimistic | Optimistic | Pessimistic |
| Clothes Dryer | 100% | 50% | 100% | 70% | 100% | 50% | 100% | 18% |
| Clothes Washer | 100% | 50% | 100% | 70% | 100% | 50% | 100% | 18% |
| DishWasher | 100% | 50% | 100% | 70% | 100% | 70% | 100% | 25% |
| Room Air Conditioner | 100% | 50% | 100% | 50% | 100% | 25% | 100% | 6% |

**Table 3-6**. Net Fraction (Percentage) of Freezer and Refrigerator On-Peak Defrost and Ice-Making Loads Available to Shift

| | Fraction of Customers Receiving Grid Signals and Communicating These to an Appliance | | Fraction of Customers Willing to Shift On-Peak Defrost Load | | Fraction of On-Peak Defrost Load that Willing Customers Shift | | Net Fraction of On-Peak Defrost Load Available to Shift | | Fraction of Customers Willing to Shift On-Peak Ice-Making Load | | Fraction of On-Peak Ice-Making Load that Willing Customers Shift | | Net Fraction of On-Peak Ice-Making Load Available to Shift | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Appliance | Optimistic | Pessimistic | Optimistic | Pessimistic | Optimistic | Pessimistic | Optimistic | Pessimistic | Optimistic | Pessimistic | Optimistic | Pessimistic | Optimistic | Pessimistic |
| Freezer | 100% | 50% | 100% | 90% | 100% | 100% | 100% | 45% | 100% | 90% | 100% | 60% | 100% | 27% |
| Refrigerator | 100% | 50% | 100% | 90% | 100% | 100% | 100% | 45% | 100% | 90% | 100% | 60% | 100% | 27% |

### 3.1.4 Load Fraction Available for Spinning Reserves

The benefits of each smart appliance depend on how much appliance load is actually available for spinning reserves (and as we will see later, the spinning reserve benefits far outweigh the peak-load shifting benefits). Similar to *Net Fraction of On-Peak Load Available to Shift*, we also define *Net Fraction of Load Available for Spinning Reserves* with the caveat that appliance load is available for spinning reserves all the time. In other words, anytime appliances are operating, they can be interrupted for a short duration, up to 10 minutes or so, either by shutting off or reducing their electricity consumption in response to a spinning-reserve request signal (for example, a dryer operating with two heating elements might continue to operate but with only one heating element on). The *Net Fraction of Load Available for Spinning Reserves* is a product of three other fractions:

4. *Fraction of Customers Receiving Grid Signals and Communicating these to an Appliance* as described above.

5. Of those customers who have the capability described in #1, only some of them will be willing to make their appliances available for spinning reserves; these we define as *Fraction of Customers Willing to Provide Spinning Reserves*.

6. Finally, among those customers who do not override a request for spinning reserves as in #2, they may not be willing to make their entire load available for spinning reserves even for a short duration. This is captured through *Fraction of Appliance Load Reduced for Spinning Reserves*.

Shown in Table 3-7 is the *Net Fraction of Load Available for Spinning Reserves* for all appliances, based on various best-case "optimistic" and worst-case "pessimistic" assumptions for the above three fractions.

**Table 3-7.** Net Fraction (Percentage) of Load Available for Spinning Reserves Available for all Appliances

| Appliance | Fraction of Customers Receiving Grid Signals and Communicating These to an Appliance | | Fraction of Customers Willing to Provide Spinning Reserves | | Fraction of Appliance Load Reduced for Spinning Reserves | | Net Fraction of Load Available for Spinning Reserves | |
|---|---|---|---|---|---|---|---|---|
| | Optimistic | Pessimistic | Optimistic | Pessimistic | Optimistic | Pessimistic | Optimistic | Pessimistic |
| Clothes Dryer | 100% | 50% | 100% | 90% | 100% | 80% | 100% | 36% |
| Clothes Washer | 100% | 50% | 100% | 90% | 100% | 50% | 100% | 23% |
| DishWasher | 100% | 50% | 100% | 90% | 100% | 50% | 100% | 23% |
| Room Air Conditioner | 100% | 50% | 100% | 90% | 100% | 80% | 100% | 36% |
| Freezer | 100% | 50% | 100% | 90% | 100% | 50% | 100% | 23% |
| Refrigerator | 100% | 50% | 100% | 90% | 100% | 50% | 100% | 23% |

### 3.1.5 Consumer Behavior Feedback Effect

Many DR projects have reported some customer energy savings, typically a few percentage points, in addition to their primary objective of reducing peak loads. While some energy savings can be attributed to physical effects of reducing load during peak load times, the primary basis for the savings is likely to be the effect of feedback provided to consumers on their usage patterns as part of these programs. Numerous studies examined by Fischer (Fischer 2008, ACEEE 2010) have shown that consumer feedback on their energy consumption habits can result in savings ranging from 5-20 percent, with a median of approximately 6 percent. Similar results have been observed in utility field studies reviewed by Faruqui (2009).

The studies reviewed provide convincing evidence that consumers will change their energy consumption behavior in response to feedback, and that the conditions surrounding feedback, such as frequency and specificity, are influential variables. The studies show that feedback tends to be most effective when it:

- is based on actual usage data
- is provided on a frequent basis (daily is better than weekly, etc.)
- involves goal setting and choice
- is provided over a year or more
- involves specific behavioral recommendations regarding appliances
- involves normative or historical comparisons.

Fischer (2008) has noted that these favor the smart grid capabilities offered by AMI and two-way communication networks, which provide an effective way of engaging the consumer continually and providing specific feedback tailored to their individual consumption patterns. This should help sustain savings over a time periods of years and decades.

While some appliances may benefit more than others, it must be emphasized that it is their collective contribution to the richness of the information that enables the value of such specific feedback. In other words, this reduction figure applies to the total home consumption, rather than to each specific appliance's usage. The benefit of the feedback accrues from the *information ecosystem* that the smart appliances create within the home. A home energy management system that can accurately estimate the consumption of each appliance using signals sent out by the collection of smart appliances may suggest, for example, that

- a new refrigerator that meets current efficiency standards would pay for itself in five years
- washing clothes in warm water instead of hot water would save you $30 a year
- a vertical-axis clothes washer with high-speed spin would save you $35 a year in hot water and $20 a year in reduced dryer energy
- The air conditioner needs service – it is running twice as much as last year in the same type of weather, and costing $200 a year extra.

While there are no studies to estimate what electricity consumption savings would be possible from each appliance as a result of energy-use feedback, we assume that there is an average reduction of 3% (pessimistic assumption) and 6% (optimistic assumption) per appliance.

## 3.2 Historical Market Prices

As mentioned earlier, both the costs involved in the operation of smart appliances and the benefits they provide are estimated in terms of historical wholesale-market data. The historical market data we consider include hourly LMP and spinning-reserve wholesale market-clearing prices over the course of a year (PJM 2006, ERCOT 2008, NYISO 2006, NYISO 2008, CAISO 2008). Based on hourly data over the course of a year, we compute various annual hourly averages for both LMP and spinning-reserve prices (these average prices will then be used later to estimate costs and benefits).

In Section 3.1.1, we presented the notion of on-peak and off-peak hours for both the optimistic and pessimistic assumptions. Based on the assumptions shown in Table 1-1 and Table 1-2 (which are applicable for all appliances except RACs), we compute annual hourly averages for LMP and spinning-reserve market-clearing prices for the optimistic and pessimistic scenarios as shown below in Table 3-8 and Table 3-9. These prices are then used later to estimate benefits and costs of all appliances except RACs under the optimistic and pessimistic scenarios respectively.

**Table 3-8**. Annual Hourly Averages of LMP and Spinning Reserve Wholesale Market Clearing Prices – Optimistic Scenario

| | Annual Average Over On-Peak Hours ($ / MWh) | | Annual Average Over Off-Peak Hours ($ / MWh) | | Annual Average Over Shift-To Hours ($ / MWh) | |
|---|---|---|---|---|---|---|
| Market | LMP | SR | LMP | SR | LMP | SR |
| PJM 2006 | 50.64 | 7.29 | 39.45 | 8.08 | 39.44 | 8.08 |
| ERCOT 2008 | 105.36 | 36.80 | 66.99 | 23.79 | 66.98 | 23.79 |
| NYISO 2008 | 115.96 | 14.84 | 92.22 | 8.56 | 92.23 | 8.56 |
| NYISO 2006 | 85.05 | 12.40 | 67.44 | 5.42 | 67.41 | 5.42 |
| CAISO 2008 | 81.99 | 13.23 | 64.94 | 3.56 | 64.95 | 3.56 |

Table 3-9. Annual Hourly Averages of LMP and Spinning Reserve Wholesale Market Clearing Prices – Pessimistic Scenario

| Market | Annual Average Over On-Peak Hours ($ / MWh) | | Annual Average Over Off-Peak Hours ($ / MWh) | | Annual Average Over Shift-To Hours ($ / MWh) | |
|---|---|---|---|---|---|---|
| | LMP | SR | LMP | SR | LMP | SR |
| PJM 2006 | 55.55 | 7.30 | 42.90 | 8.29 | 42.89 | 8.29 |
| ERCOT 2008 | 118.93 | 37.42 | 72.86 | 25.57 | 72.86 | 25.58 |
| NYISO 2008 | 120.41 | 14.38 | 94.80 | 9.16 | 94.81 | 9.16 |
| NYISO 2006 | 93.91 | 16.02 | 72.50 | 7.62 | 72.50 | 7.62 |
| CAISO 2008 | 88.03 | 14.90 | 68.56 | 4.29 | 68.56 | 4.29 |

For estimating the costs and benefits of RACs, we consider average wholesale market-clearing prices only over the months during which peak hours are expected to occur. Recall from Section 3.1.1, our assumption is that RACs operate only for 4 months (summer months: June-September) during the course of a year, but under the optimistic scenario (Table 3-3), peak hours occur on all days of a week during those months, and under the pessimistic scenario (Table 3-4); they occur only on the weekdays of those months. Based on these assumptions, we compute hourly averages of LMP and spinning-reserve market-clearing prices for the optimistic and pessimistic scenarios as shown below in Table 3-10 and Table 3-11 respectively.

**Table 3-10**. Hourly Averages of LMP and Spinning-Reserve Wholesale Market-Clearing Prices Over Months June through September - Optimistic Scenario

| Market | Annual Average Over On-Peak Hours ($ / MWh) | | Annual Average Over Off-Peak Hours ($ / MWh) | | Annual Average Over Shift-To Hours ($ / MWh) | |
|---|---|---|---|---|---|---|
| | LMP | SR | LMP | SR | LMP | SR |
| PJM 2006 | 66.12 | 4.31 | 36.59 | 3.54 | 36.58 | 3.54 |
| ERCOT 2008 | 126.97 | 36.80 | 73.33 | 23.79 | 73.33 | 23.79 |
| NYISO 2008 | 151.26 | 14.84 | 100.09 | 8.56 | 100.09 | 8.56 |
| NYISO 2006 | 115.97 | 12.40 | 64.36 | 5.42 | 64.36 | 5.42 |
| CAISO 2008 | 109.26 | 13.23 | 69.76 | 3.56 | 69.76 | 3.56 |

Table 3-11. Hourly Averages of LMP and Spinning-Reserve Wholesale Market-Clearing Prices Over Months June through September - Pessimistic Scenario

| Market | Annual Average Over On-Peak Hours ($ / MWh) | | Annual Average Over Off-Peak Hours ($ / MWh) | | Annual Average Over Shift-To Hours ($ / MWh) | |
|---|---|---|---|---|---|---|
| | LMP | SR | LMP | SR | LMP | SR |
| PJM 2006 | 74.45 | 4.00 | 41.60 | 3.33 | 41.59 | 3.33 |
| ERCOT 2008 | 136.50 | 37.42 | 80.23 | 25.57 | 80.23 | 25.58 |
| NYISO 2008 | 164.45 | 14.38 | 104.01 | 9.16 | 104.01 | 9.16 |
| NYISO 2006 | 142.54 | 16.02 | 73.03 | 7.62 | 73.03 | 7.62 |
| CAISO 2008 | 123.28 | 14.90 | 73.79 | 4.29 | 73.79 | 4.29 |

The average prices shown above in Table 3-10 and Table 3-11will be used later to estimate costs and benefits of RACs under the optimistic and pessimistic scenarios respectively.

In our discussion of on-peak hours in Section 3.1.1, we presented the notion of "shift-to" hours. In general, the "shift-to" hours could be different from off-peak hours, but in our assumptions from Table 3-1, Table 3-2, Table 3-3, and Table 3-4, we note that "shift-to" hours are in fact all of the off-peak hours. Hence, from Table 3-8, Table 3-9, Table 3-10, and Table 3-11, we note that average prices over the shift-to hours are the same as those over off-peak hours.

## 3.3 Appliance Load Shapes

In order to estimate what the annual operating expenses would be for each appliance, it is required to get a measure of the average electricity consumption of each appliance over the course of each hour on an average day. This is what is referred to as "appliance load shape." An "average" day could be an average annual day, an average summer day, etc. For the purpose of this report, we utilize the load shapes developed as part of the End-Use Load and Consumer Assessment Program (Pratt et al. 1989). In the sections to follow, we present the load shapes for each appliance.

### 3.3.1 Clothes Dryer (CD) Load Shape

The hourly electricity consumption by a dryer on an average annual day is shown below in Table 3-12.

**Table 3-12**. ELCAP CD Hourly Consumption on an Average Annual Day

| Hour | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| kW-hr/hr | 0.0346 | 0.0149 | 0.0086 | 0.0060 | 0.0067 | 0.0180 | 0.0494 | 0.0907 | 0.1257 | 0.1744 | 0.2083 | 0.2161 |
| Hour | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 |
| kW-hr/hr | 0.2023 | 0.1901 | 0.1720 | 0.1644 | 0.1657 | 0.1666 | 0.1607 | 0.1584 | 0.1657 | 0.1709 | 0.1394 | 0.0810 |

The CD load shape based on the data shown in Table 3-12 in shown in Figure 3.1 below.

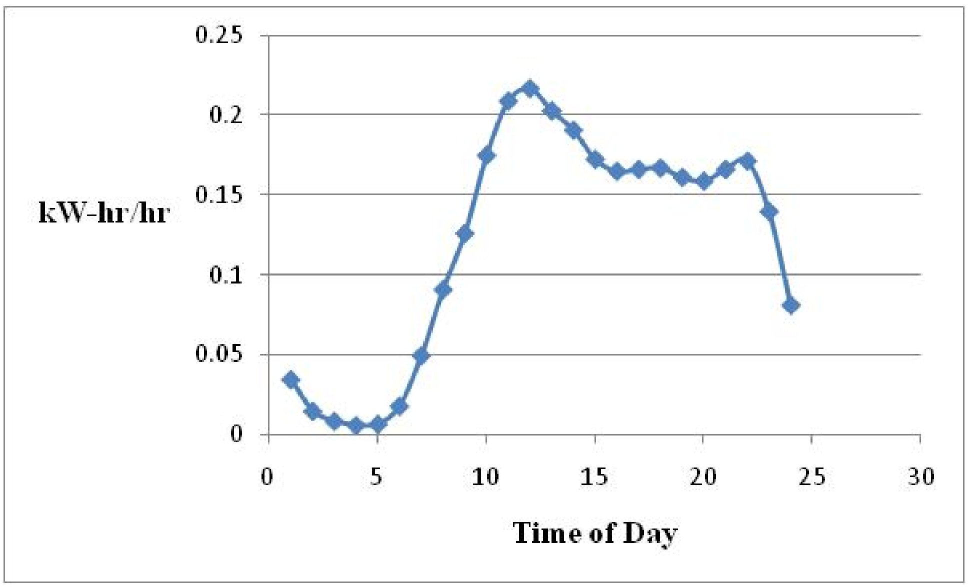


**Figure 3.1**. ELCAP Dryer Load Shape for an Average Annual Day

### 3.3.2 Dishwasher Load Shape

The hourly electricity consumption by a dishwasher on an average annual day is shown below in Table 3-13.

**Table 3-13**. ELCAP Dishwasher Hourly Consumption on an Average Annual Day

| Hour | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| kW-hr/hr | 0.0075 | 0.0034 | 0.0017 | 0.0014 | 0.0012 | 0.0031 | 0.0061 | 0.0111 | 0.0169 | 0.0190 | 0.0177 | 0.0149 |
| Hour | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 |
| kW-hr/hr | 0.0144 | 0.0153 | 0.0132 | 0.0123 | 0.0133 | 0.0159 | 0.0270 | 0.0330 | 0.0276 | 0.0230 | 0.0188 | 0.0135 |

The dishwasher load shape based on the data shown in Table 3-13 is shown in Figure 3.2 below.

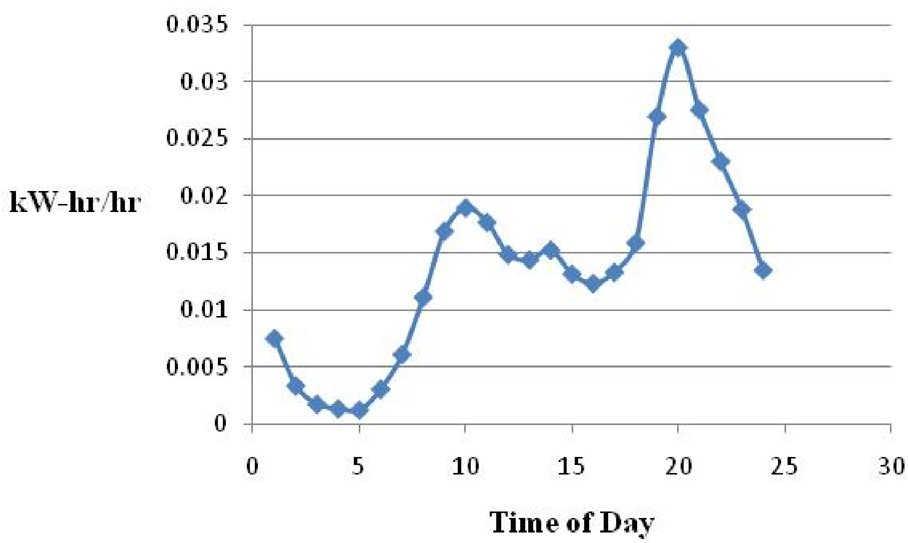


**Figure 3.2**. ELCAP Dishwasher Load Shape for an Average Annual Day

### 3.3.3 RAC Load Shape

In the case of a RAC, we only consider electricity consumption during the summer months (June-September). The hourly electricity consumption by a RAC on an average summer day is shown below in Table 3-14.

**Table 3-14**. ELCAP RAC Hourly Consumption on an Average Summer Day

| Hour | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| kW-hr/hr | 0.1200 | 0.1000 | 0.0900 | 0.0800 | 0.0800 | 0.0900 | 0.1271 | 0.1600 | 0.1757 | 0.1929 | 0.2129 | 0.2257 |
| Hour | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 |
| kW-hr/hr | 0.2557 | 0.2929 | 0.3329 | 0.3800 | 0.4271 | 0.4571 | 0.4671 | 0.4271 | 0.3571 | 0.2871 | 0.2271 | 0.1600 |

The RAC load shape based on the data shown in Table 3-14 is shown in Figure 3.3 below.

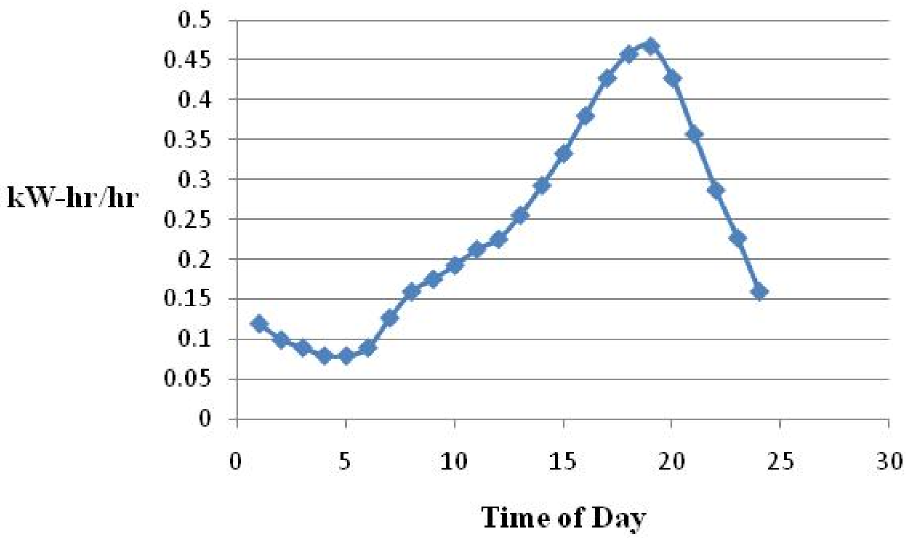


**Figure 3.3**. ELCAP RAC Load Shape for an Average Summer Day

### 3.3.4 Freezer Load Shape

The hourly electricity consumption by a freezer on an average annual day is shown below in Table 3-15.

**Table 3-15**. ELCAP Freezer Hourly Consumption on an Average Annual Day

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Hour** | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| **kW-hr/hr** | 0.1733 | 0.1739 | 0.1716 | 0.1671 | 0.1674 | 0.1654 | 0.1610 | 0.1580 | 0.1597 | 0.1627 | 0.1656 | 0.1709 |
| **Hour** | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 |
| **kW-hr/hr** | 0.1776 | 0.1811 | 0.1821 | 0.1831 | 0.1873 | 0.1917 | 0.1923 | 0.1900 | 0.1890 | 0.1860 | 0.1807 | 0.1750 |

The freezer load shape based on the data shown in Table 3-15 is shown in Figure 3.4 below.

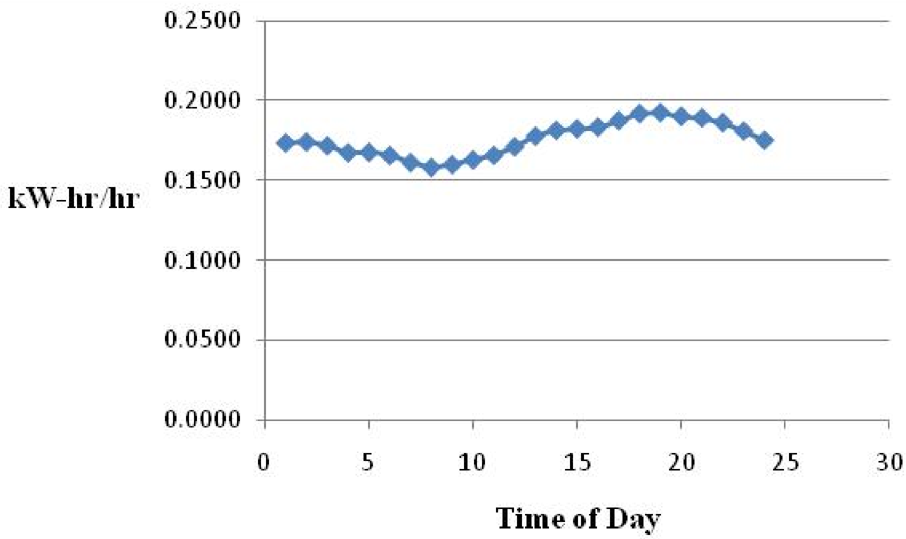


**Figure 3.4**. ELCAP Freezer Load Shape for an Average Annual Day

### 3.3.5 Refrigerator Load Shape

The hourly electricity consumption by a refrigerator on an average annual day is shown below in Table 3-16.

**Table 3-16**. ELCAP Refrigerator Hourly Consumption on an Average Annual Day

| Hour | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| kW-hr/hr | 0.1636 | 0.1603 | 0.1553 | 0.1510 | 0.1483 | 0.1511 | 0.1581 | 0.1627 | 0.1644 | 0.1666 | 0.1656 | 0.1663 |
| Hour | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 |
| kW-hr/hr | 0.1736 | 0.1741 | 0.1727 | 0.1751 | 0.1823 | 0.1949 | 0.2017 | 0.1963 | 0.1919 | 0.1883 | 0.1806 | 0.1703 |

The refrigerator load shape based on the data shown in Table 3-16 is shown in Figure 3.5 below.

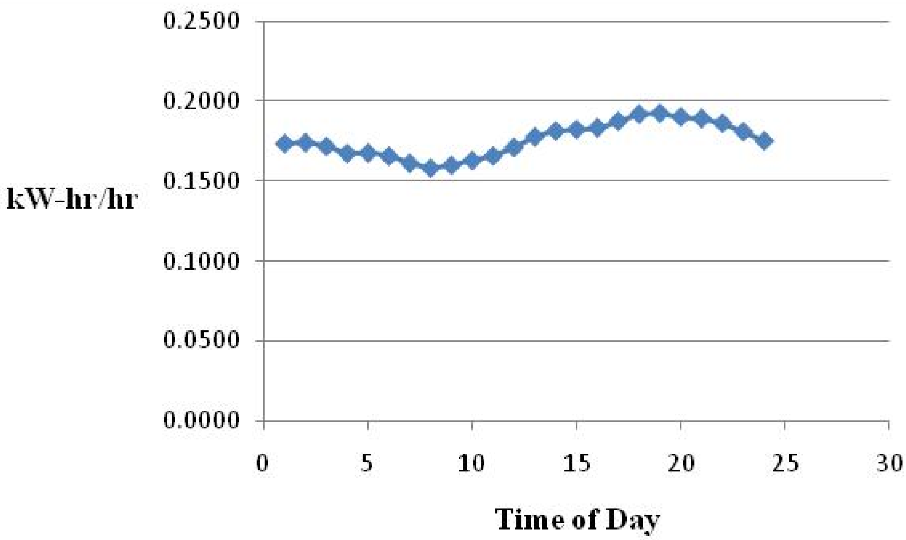


**Figure 3.5**. ELCAP Refrigerator Load Shape for an Average Annual Day

### 3.3.6 Clothes Washer (CW) Load Shape

The hourly electricity consumption by a CW on an average annual day is shown below in Table 3-17.

**Table 3-17**. ELCAP CW Hourly Consumption on an Average Annual Day

| Hour | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| kW-hr/hr | 0.0029 | 0.0019 | 0.0015 | 0.0014 | 0.0018 | 0.0030 | 0.0054 | 0.0112 | 0.0177 | 0.0223 | 0.0238 | 0.0226 |
| Hour | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 |
| kW-hr/hr | 0.0203 | 0.0180 | 0.0156 | 0.0145 | 0.0151 | 0.0156 | 0.0157 | 0.0155 | 0.0154 | 0.0144 | 0.0103 | 0.0059 |

The CW load shape based on the data shown in Table 3-16 is shown in Figure 3.6 below.

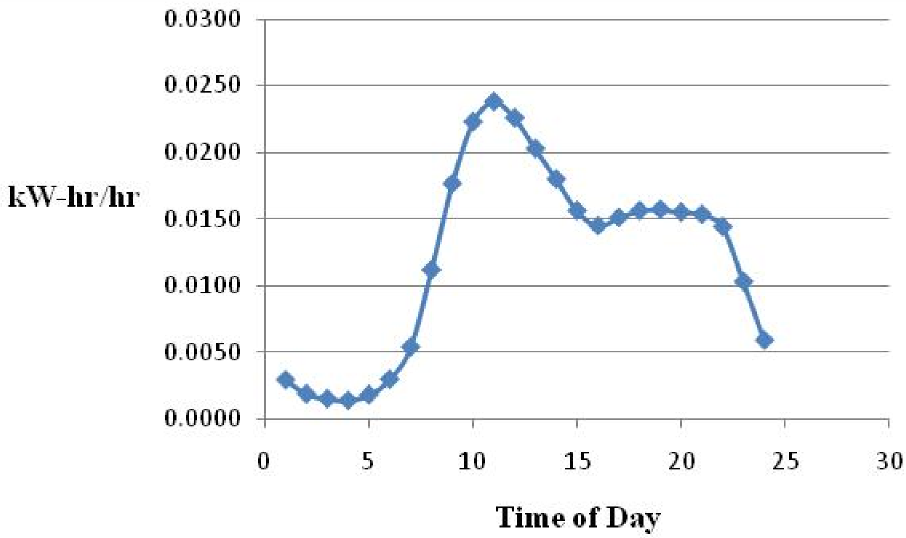


**Figure 3.6**. ELCAP CW Load Shape for an Average Annual Day

## 3.4 Smart Appliance Benefits Based on Wholesale Power Production Costs

In this section, we present the analytical model used to estimate the benefits of the smart appliances we consider in this report. The benefits are estimated in terms of the savings in wholesale power production costs.

First, we define below various quantities needed in our calculations.

### 3.4.1 Notation

Let *fp* denote the ratio of total annual electricity consumption during on-peak hours to total annual electricity consumption over all hours for each appliance (estimated from definitions of on-peak and off-peak hours listed in 3.1.1, and ELCAP load shapes presented in 3.3).

This ratio depends on the definition of on-peak hours and the number of days in a year those on-peak hours are in effect (say $N_p$) and is given by

$$f_p \quad = \quad (l_p * N_p) / (365 * l)$$

where $l_p$= daily on-peak consumption (load), and $l$ = daily total consumption as given by the ELCAP load shape. For example, in the case of a dryer, we have $l_p$= 1.06 kWh/day, $l$ = 2.89 kW/day, and $N_p$ = 365, giving us $f_p$ = 0.37.

Let

$L$[8] = Total annual electricity consumption for each appliance (see Section 3.1.2)

Then

| | | |
|---|---|---|
| Total annual on-peak hours of electricity consumption for each appliance | $= f_p * L$ | (1) |

and

| | | |
|---|---|---|
| Total annual off-peak hours electricity consumption for each appliance | $= (1 - f_p) * L$ | (2) |

In Section 3.2, we presented hourly average wholesale market-clearing prices, both LMP and spinning reserves. In order to express costs and benefits in terms of those prices, let

- $C_{ep}$ = Hourly average energy cost for on-peak hours (LMP)
- $C_{eop}$ = Hourly average energy cost for off-peak hours (LMP)
- $C_{est}$ = Hourly average energy cost for “shift-to” hours (LMP)
- $C_{srp}$ = Hourly average cost of spinning reserves for on-peak hours
- $C_{srop}$ = Hourly average cost of spinning reserves for off-peak hours
- $C_{srst}$ = Hourly average cost of spinning reserves for “shift-to” hours

Note that if, as assumed in Section 3.1.1, the “shift-to” hours are the same as the off-peak hours, then

$$C_{eop} = C_{est}, \text{ and } C_{srop} = C_{srst}.$$

[8] In the case of CWs and DWs, L must account for the fact that CWs and DWs utilize resident hot water heaters for their hot water supply, and not all hot water heaters are electricity based. Some are gas fired. See the CW and DW results in Sections 4.6 and 4.7 where we take this into account.

Finally, let *p*% denote the *Net Fraction of On-Peak Load Available to Shift* peak load-shift fraction discussed in Section 3.1.3.

With all of the above definitions, we now evaluate the benefits (power production cost savings) of smart appliances to peak load shifting and spinning reserves. We first consider peak load shifting.

### 3.4.2 Smart Appliance Benefits: Peak Load Shifting

The operation of any appliance would incur a certain annual wholesale market cost. However, a smart appliance, by virtue of its ability to shift its operation from peak hours to off-peak or "shift-to" hours, will result in savings in wholesale market costs. This is due to the fact that off-peak wholesale prices are typically lower than on-peak wholesale prices. We express these savings in terms of the various quantities we defined above.

The annual energy cost $C_A$ for running an appliance in normal mode is the sum of the cost of on-peak consumption and the cost of off-peak consumption. Using the expressions for on-peak consumption (Equation 1) and off-peak consumption (Equation 2), we get

$$C_A = Cep * fp * L + Ceop * (1 - fp) * L \qquad (3)$$

Annual energy cost $C_{AST}$ for running an appliance with peak load shifted to "shift-to" hours (peak load will be valued at annual hourly average energy cost for "shift-to" hours) will be:

$$C_{AST} = Cest * fp * L + Ceop * (1 - fp) * L \qquad (4)$$

Maximum annual savings ( $S_{PLS}$ **)** in energy cost resulting from 100% appliance peak load shifted to "shift to" hours: Equation 3 – Equation 4.

$$S_{PLS} = fp * L * (Cep - Cest) \qquad (5)$$

Annual savings ( $S_{PLS}$ **)** in energy cost resulting from *p*% of appliance peak load shifted to "shift to" hours is then given by

$$S_{PLS} = p * fp * L * (Cep - Cest) \qquad (6)$$

### 3.4.3 Smart Appliance Benefits: Spinning Reserves

In Section 2.2, we motivated the use of smart appliances to provide spinning reserves. To reiterate very briefly, spinning reserves are typically provided by generators that are already synchronized to the grid, by releasing capacity set aside in response to a contingency signal from an ISO/RTO. We recap below the characteristic features of spinning reserves

Spinning reserves are in general a part of contingency reserves (which include non-spinning reserves) that are set aside as unused capacity to be invoked in the event of a contingency such as loss of a generator or a transmission line. Spinning reserves need to be maintained ALL THE TIME, i.e., every hour, every day, throughout the year.

1. Spinning reserves are typically provided by generators that are already synchronized to the grid, by operating them below their rated capacity, and releasing this unused capacity in response to a contingency signal from an ISO/RTO. NERC requires that spinning reserves be released within 10 minutes of receiving a contingency signal.
2. While there is no fixed requirement on how long spinning reserves must be deployed once called upon, historically, it has been observed in various ISO/RTO markets that , that if called upon, generators must provide this installed capacity for about 10 minutes, by which time other reserves are deployed. Thus, instead of generators, this same function can be provided by a smart appliance that is ready and willing to reduce load temporarily in response to a signal to do so.
3. Note: The premise in this report is that instead of generators supplying spinning reserves, smart appliances curtail their operation for 10 minutes in response to a contingency signal. Thus, the ELCAP appliance load shapes presented in 3.3 serve as the available "capacity" in the sense that at any time an appliance is operating, it is available for curtailment, and in this sense it is installed capacity for spinning reserves.
4. Spinning reserves are basically an opportunity cost to power producers; they bid spinning reserve capacity in the open wholesale market. Power producers are compensated for spinning reserves based on the capacity they have set aside each hour for spinning reserves, and the market clearing price for that hour (units: $/MW-hr). Note that this is slightly different from $/MWH (which is cost for energy delivered).

A more formal description of how spinning reserves are valued is as follows. Let $c_i$ denote the capacities set aside for spinning reserves for each hour $i$ ($i$ = 1, 2, …). Let $p_i$ denote the wholesale market-clearing price for spinning reserves for the hour $i$. Then the value $V_{SR}$ of spinning reserves at which power producers are compensated is given by

$$V_{SR} = \sum_i c_i * p_i \qquad (7)$$

As an example, assume an average cost of spinning reserves of $10/MW-hr (it varies by market and from hour to hour). Then if the average all-hours installed spinning reserve capacity is, say, 10 MW-hr/hr, then the annual cost of spinning reserves is

8760 (hours/year) * 10 MW-hr/hr * $10/MW-hr = $876,000/year

For our purpose, we rearrange Equation 7 as follows:

$$V_{SR} = V_{SRP} + V_{SROP} \qquad (8)$$

where $V_{SRP}$ and $V_{SROP}$ are spinning-reserve values during on-peak and off-peak hours, respectively, and are given by

$$V_{SRP} = \sum_{i \in \{on-peak\ hours\}} c_i * p_i \qquad (9)$$

$$V_{SROP} = \sum_{i \in \{off-peak\ hours\}} c_i * p_i \qquad (10)$$

If we replace hourly on-peak and off-peak wholesale spinning-reserve market-clearing prices with their average values $C_{srp}$ and $C_{srop}$, respectively, it follows that Equation 9 and Equation 10 can be re-written as

$$V_{SRP} = C_{srp} * \sum_{i \in \{on-peak\ hours\}} c_i \qquad (11)$$

$$V_{SROP} = C_{srop} * \sum_{i \in \{off-peak\ hours\}} c_i \qquad (12)$$

Now, let us consider smart appliances in place of generators as sources for spinning reserves. Then, from Equations 1 and 2, which were derived based on ELCAP load shapes and annual appliance consumption $L$, we have

$$\sum_{i \in \{peak\ hours\}} c_i = f_p * L \qquad (13)$$

and

$$\sum_{i \in \{off-peak\ hours\}} c_i = (1 - f_p) * L \qquad (14)$$

It then follows from Equations 11 and 12 that,

$$V_{SRP} = C_{srp} * f_p * L \qquad (15)$$

and

$$V_{SROP} = C_{srop} * (1 - f_p) * L \qquad (16)$$

Now if *p*% of appliance peak load were shifted to "shift-to" hours, then it follows that appliance load available during on-peak hours is reduced by a factor of (*1-p*), and the remaining peak load is available as additional spinning reserves during off-peak hours but valued at $C_{srst}$. Thus,

$$V_{SRP} = (1 - p) * f_p * L * C_{srp} \qquad (17)$$

and

$$V_{SROP} = p * f_p * L * C_{srst} + (1 - f_p) * L * C_{srop} \qquad (18)$$

Thus, the total spinning reserve value $V_{SR}$ from each smart appliance is Equation 17 + Equation 18, and after some re-arranging of terms is given by

$$V_{SR} = f_p * L * (C_{srp} - C_{srop}) + L * C_{srop} - p * f_p * L * (C_{srp} - C_{srst}) \qquad (19)$$

Note that in deriving Equation (19), we have assumed that all of an appliance annual electricity consumption *L* is available for spinning reserves. In general, $V_{SR}$ must be discounted by the factor *Net Fraction of Load Available for Spinning Reserves* which was described in Section 3.1.4.

# 4.0 Smart Appliance Benefit-to-Cost Ratios

In this section we first examine smart appliance benefit-to-cost ratio in general. Then, we present the benefit-to-cost ratios (expressed as percentages) for each smart appliance.

## 4.1 Benefits-to-Cost Ratio: General

Recall that in this report, by "benefits" we mean savings in wholesale power-production costs. In Section 3.4.2, we evaluated the benefits $S_{PLS}$ of smart appliances resulting from peak-load shifting (Equation 6). In Section 3.4.3, we evaluated the benefits $V_{SR}$ resulting from smart appliances serving as sources of spinning reserves (Equation 19). The net smart-appliance benefits, B, are found by adding Equation 6 and Equation 19, and rearranging terms as follows:

$$B = f_p * L * (C_{srp} - C_{srop}) + L * C_{srop} + p * f_p * L * (C_{ep} - C_{est} - C_{srp} + C_{srst}) \quad (20)$$

For the purpose of this report, the "cost" of a smart appliance is defined as follows. Recall, AHAM and other stakeholders are petitioning the EPA for a "credit" on current appliance standards, so that appliance manufactures can use that credit to invest in smart appliances and spur the market for smart appliances. Let this credit be denoted by *CR*. (The current value of *CR* as per the petition is 5%). Now, based on current appliance standards, the annual operating cost $C_A$ for each appliance is given by Equation 3, which we reproduce here for convenience:

$$C_A = C_{ep} * f_p * L + C_{eop} * (1 - f_p) * L \quad (21)$$

The credit *CR* is applied against $C_A$, which is interpreted as the "cost" *C*, and is given by

$$C = C_A * [C_{ep} * f_p * L + C_{eop} * (1 - f_p) * L] \quad (22)$$

The benefit-to-cost ratio is thus given by

$$B/C = [f_p * (C_{srp} - C_{srop}) + C_{srop} + p * f_p * (C_{ep} - C_{est} - C_{srp} + C_{srst})] \Big/ CR * [C_{ep} * f_p + C_{eop} * (1 - f_p)] \quad (23)$$

We make three important observations from Equations 20, 22, and 23:

1. The absolute values of both benefits and costs depend on all the quantities we have in our assumptions as described in Section 3.1.
2. However, the benefit-to-cost ratio given by Equation 23 is independent of each smart appliance's annual electricity consumption. It of course depends on the load shape (the parameter $f_p$ ), load shift fraction *p*, smart-appliance credit CR, and wholesale market-clearing prices.
3. The benefit-to-cost ratio gives an indication of how valuable the smart appliance benefits are with respect to cost. We expect the ratio to be greater than or equal to 1 (or 100%) in order for the credit to be cost-effective.

We now utilize the cost benefit model developed so far and present the benefit-to-cost ratios of each appliance, expressed as percentages. All the tables that will be presented henceforth are taken from the smart-appliance cost/benefit analysis spreadsheet that was developed as part of this project[1].

## 4.2 Benefit-to-Cost Ratios: Smart Clothes Dryers (CD)

In this section, we estimate the benefit-to-cost ratio of smart CDs in various markets based on both optimistic and pessimistic sets of assumptions.

### 4.2.1 High-End Optimistic Results

We first present below in Table 4-1 the annual on-peak and off-peak electricity consumption based on the optimistic assumptions presented in Section 3.1.

**Table 4-1**. CD On-Peak and Off-Peak Consumption Based on ELCAP Average Annual Day Load Shape and Optimistic Assumptions

| ELCAP (1990) Dryer Load Shape | | | | | 2010 Annual Dryer On-Peak and Off-Peak Consumption | | |
|---|---|---|---|---|---|---|---|
| Load Shape: | Average Day | Annual | | | Total Annual Consumption (2010) | Annual On-Peak Consumption (2010) | Annual Off-Peak Consumption (2010) |
| | Daily Total | On-Peak | Avg. No. of On-Peak Days/Year | Annual On-Peak To Total Ratio | | | |
| Start, Hour Ending: | 1 | 13 | | | | | |
| Through Hour Ending: | 24 | 18 | | | | | |
| | (kWh/day) | (kWh/day) | | | (kWh/yr) | (kWh/yr) | (kWh/yr) |
| | 2.89 | 1.06 | 365 | 0.37 | 658 | 242 | 416 |

Based on the data shown in Table 4-1, high-end wholesale power production cost savings using smart CDs for peak load shifting are shown in Table 4-2 below.

**Table 4-2**. Wholesale Cost Savings from Using Smart CDs for Peak Load Shifting – Optimistic View

| | Annual Hourly Energy Market Clearing Prices | | | Annual Energy Cost (No Load Shift) | | Annual Energy Cost Savings from 100% Peak Load Shift | |
|---|---|---|---|---|---|---|---|
| | Avg. On-Peak | Avg. Off-Peak | Avg. Shift-To Hours | On-Peak | Off-Peak | On-Peak Energy Moved to "Shift To" Hours | Savings |
| Market and Year | ($/MWh) | ($/MWh) | ($/MWh) | ($/yr) | ($/yr) | (kWh/yr) | ($/yr) |
| PJM 2006 | $50.64 | $39.44 | $39.44 | $12.23 | $16.43 | 241.54 | $2.70 |
| ERCOT 2008 | $105.56 | $67.09 | $67.09 | $25.50 | $27.94 | 241.54 | $9.29 |
| NYISO 2008 | $115.97 | $92.25 | $92.27 | $28.01 | $38.42 | 241.54 | $5.73 |
| NYISO 2006 | $85.05 | $67.44 | $67.41 | $20.54 | $28.09 | 241.54 | $4.26 |
| CAISO 2008 | $82.11 | $65.01 | $65.02 | $19.83 | $27.07 | 241.54 | $4.13 |

[1] The spreadsheets will be made available upon request.

The high-end wholesale cost savings from using smart CDs for providing spinning reserves is shown in Table 4-3 below.

**Table 4-3**. Wholesale Cost Savings from Using Smart CDs for Spinning Reserves – Optimistic View

| | Annual Hourly SR Market Clearing Prices | | | Annual Dryer SR Market Value | | |
|---|---|---|---|---|---|---|
| | Avg. On-Peak | Avg. Off-Peak | Avg. Shift-To Hours | On Peak: From Dryer Load After 100% Shifted | Off-Peak: From Dryer Off-Peak Load + 100% Load shifted from Peak to 'Shift To' Hours | Total Spinning Reserve Cost Savings |
| Market and Year | ($/MWh) | ($/MWh) | ($/MWh) | ($/yr) | ($/yr) | ($/yr) |
| PJM 2006 | $7.29 | $8.08 | $8.08 | $0.00 | $5.32 | $5.32 |
| ERCOT 2008 | $36.85 | $23.76 | $23.76 | $0.00 | $15.63 | $15.63 |
| NYISO 2008 | $14.84 | $8.56 | $8.56 | $0.00 | $5.63 | $5.63 |
| NYISO 2006 | $12.40 | $5.42 | $5.42 | $0.00 | $3.57 | $3.57 |
| CAISO 2008 | $13.26 | $3.56 | $3.57 | $0.00 | $2.35 | $2.35 |

The additional 6% optimistic electricity consumption and cost savings resulting from providing energy-use feedback to customers is shown below in Table 4-4.

**Table 4-4**. Additional 6% Savings Resulting from CD Consumption Feedback to Customers

| Market and Year | (kWh/yr) | ($/yr) |
|---|---|---|
| PJM 2006 | 39 | $1.72 |
| ERCOT 2008 | 39 | $3.21 |
| NYISO 2008 | 39 | $3.99 |
| NYISO 2006 | 39 | $2.92 |
| CAISO 2008 | 39 | $2.81 |

Finally, the high-end benefits (wholesale cost savings resulting from peak-load shifting, spinning reserves, consumer feedback, and their combined total) and cost (5% credit) are shown below in Table 4-5 below, expressed as benefits-to-cost percentages; and the percentages of total benefits individually attributable to peak-load shifting, spinning reserves, and feedback effect are shown below in Table 4-6.

**Table 4-5**. Smart CD Benefits (Peak Load Shift + Spinning Reserves + Feedback Effect)-to-Cost Ratio – Optimistic View

| Market and Year | Grid Operational Cost Savings (Benefits) | Cost of Additional Energy Consumption at 5% Credit | Load Shift Benefits to Cost Ratio | Spinning Reserves Benefits to Cost Ratio | Feedback Effect Benefits to Cost Ratio | Total Benefits to Cost Ratio |
|---|---|---|---|---|---|---|
| | ($/yr) | ($/yr) | (-) | (-) | (-) | (-) |
| PJM 2006 | $9.74 | $1.43 | 189% | 371% | 120% | **680%** |
| ERCOT 2008 | $28.13 | $2.67 | 348% | 587% | 120% | **1054%** |
| NYISO 2008 | $15.35 | $3.32 | 173% | 170% | 120% | **462%** |
| NYISO 2006 | $10.75 | $2.43 | 175% | 147% | 120% | **442%** |
| CAISO 2008 | $9.27 | $2.34 | 176% | 100% | 120% | **396%** |

Table 4-6. Percentage of Total CD Benefits Attributable to Load Shift, Spinning Reserves, and Feedback Effect - Optimistic View

| Market and Year | Peak-Load Shifting | Spinning Resreves | Feedback Effect |
|---|---|---|---|
| PJM 2006 | 28% | 55% | 18% |
| ERCOT 2008 | 33% | 56% | 11% |
| NYISO 2008 | 37% | 37% | 26% |
| NYISO 2006 | 40% | 33% | 27% |
| CAISO 2008 | 44% | 25% | 30% |

Thus, as can be observed from Table 4-5, the benefit-to-cost ratios overwhelmingly exceed 100% in all markets.

### 4.2.2 Low-End Pessimistic Results

We first present below in Table 4-7 the annual on-peak and off-peak electricity consumption based on the optimistic assumptions presented in Section 3.1.

**Table 4-7**. CD On-Peak and Off-Peak Consumption Based on ELCAP Average Annual Day Load Shape and Pessimistic Assumptions

| ELCAP (1990) Dryer Load Shape | | | | | 2010 Annual Dryer On-Peak and Off-Peak Consumption | | |
|---|---|---|---|---|---|---|---|
| Load Shape: | Average Day | Annual | | | Total Annual Consumption (2010) | Annual On-Peak Consumption (2010) | Annual Off-Peak Consumption (2010) |
| | Daily Total | On-Peak | Avg. No. of On-Peak Days/Year | Annual On-Peak To Total Ratio | | | |
| Start, Hour Ending: | 1 | 14 | | | | | |
| Through Hour Ending: | 24 | 17 | | | | | |
| | (kWh/day) | (kWh/day) | | | (kWh/yr) | (kWh/yr) | (kWh/yr) |
| | 2.89 | 0.69 | 261 | 0.17 | 658 | 113 | 545 |

Based on the data shown in Table 4-7, high-end wholesale power production cost savings using smart CDs for peak load shifting are shown below in Table 4-8.

**Table 4-8**. Wholesale Cost Savings from Using Smart CDs for Peak-Load Shifting – Pessimistic View

| | Annual Hourly Energy Market Clearing Prices | | | Annual Energy Cost (No Load Shift) | | Annual Energy Cost Savings from 18% Peak Load Shift | |
|---|---|---|---|---|---|---|---|
| | Avg. On-Peak | Avg. Off-Peak | Avg. Shift-To Hours | On-Peak | Off-Peak | On-Peak Energy Moved to "Shift To" Hours | Savings |
| Market and Year | ($/MWh) | ($/MWh) | ($/MWh) | ($/yr) | ($/yr) | (kWh/yr) | ($/yr) |
| PJM 2006 | $55.55 | $42.90 | $42.89 | $6.25 | $23.40 | 19.70 | $0.25 |
| ERCOT 2008 | $118.93 | $72.86 | $72.86 | $13.39 | $39.74 | 19.70 | $0.91 |
| NYISO 2008 | $120.41 | $94.80 | $94.81 | $13.55 | $51.71 | 19.70 | $0.50 |
| NYISO 2006 | $93.91 | $72.50 | $72.50 | $10.57 | $39.55 | 19.70 | $0.42 |
| CAISO 2008 | $88.03 | $68.56 | $68.56 | $9.91 | $37.39 | 19.70 | $0.38 |

The low-end wholesale cost savings from using smart CDs for providing spinning reserves is shown in Table 4-9 below.

**Table 4-9**. Wholesale Cost Savings from Using Smart CDs for Spinning Reserves – Pessimistic View

| | Annual Hourly SR Market Clearing Prices | | | Annual Dryer SR Market Value | | |
|---|---|---|---|---|---|---|
| | Avg. On-Peak | Avg. Off-Peak | Avg. Shift-To Hours | On Peak: From Dryer Load After 18% Shifted | Off-Peak: From Dryer Off-Peak Load + 18% Load shifted from Peak to 'Shift To' Hours | Total Spinning Reserve Cost Savings |
| Market and Year | ($/MWh) | ($/MWh) | ($/MWh) | ($/yr) | ($/yr) | ($/yr) |
| PJM 2006 | $7.30 | $8.29 | $8.29 | $0.24 | $1.69 | $1.93 |
| ERCOT 2008 | $37.42 | $25.57 | $25.58 | $1.25 | $5.20 | $6.45 |
| NYISO 2008 | $14.38 | $9.16 | $9.16 | $0.48 | $1.86 | $2.34 |
| NYISO 2006 | $16.02 | $7.62 | $7.62 | $0.54 | $1.55 | $2.09 |
| CAISO 2008 | $14.90 | $4.29 | $4.29 | $0.50 | $0.87 | $1.37 |

The additional 3% pessimistic electricity consumption and cost savings resulting from providing energy-use feedback to customers is shown below in Table 4-10.

**Table 4-10**. Additional 3% Savings Resulting from CD Consumption Feedback to Customers

| Market and Year | (kWh/yr) | ($/yr) |
|---|---|---|
| PJM 2006 | 20 | $0.89 |
| ERCOT 2008 | 20 | $1.59 |
| NYISO 2008 | 20 | $1.96 |
| NYISO 2006 | 20 | $1.50 |
| CAISO 2008 | 20 | $1.42 |

Finally, the low-end benefits (wholesale cost saving resulting from peak-load shifting, spinning reserves, consumer feedback, and their combined total) and cost (5% credit) are shown in

Table 4-11 below, expressed as benefits-to-cost percentages; and the percentage of these benefits individually attributable to peak-load shifting, spinning reserves, and feedback effect are shown below in Table 4-12.

Table 4-11**.** Smart CD Benefit (Peak Load Shift + Spinning Reserves + Feedback Effect)-to-Cost Ratio – Pessimistic View

| | Grid Operational Cost Savings (Benefits) | Cost of Additional Energy Consumption at 5% Credit | Load Shift Benefits to Cost Ratio | Spinning Reserves Benefits to Cost Ratio | Feedback Effect Benefits to Cost Ratio | Total Benefits to Cost Ratio |
|---|---|---|---|---|---|---|
| Market and Year | ($/yr) | ($/yr) | (-) | (-) | (-) | (-) |
| PJM 2006 | $3.07 | $1.48 | 17% | 130% | 60% | **207%** |
| ERCOT 2008 | $8.96 | $2.66 | 34% | 243% | 60% | **337%** |
| NYISO 2008 | $4.81 | $3.26 | 15% | 72% | 60% | **147%** |
| NYISO 2006 | $4.01 | $2.51 | 17% | 83% | 60% | **160%** |
| CAISO 2008 | $3.17 | $2.37 | 16% | 58% | 60% | **134%** |

Table 4-12. Percentage of Total CD Benefits Attributable to Load Shift, Spinning Reserves, and Feedback Effect - Pessimistic View

| Market and Year | Peak-Load Shifting | Spinning Resreves | Feedback Effect |
|---|---|---|---|
| PJM 2006 | 8% | 63% | 29% |
| ERCOT 2008 | 10% | 72% | 18% |
| NYISO 2008 | 10% | 49% | 41% |
| NYISO 2006 | 11% | 52% | 37% |
| CAISO 2008 | 12% | 43% | 45% |

Thus, as can be observed from

Table 4-11, the benefit–to-cost ratios exceed 100% even for the pessimistic set of assumptions in all markets.

## 4.3 Benefit-to-Cost Ratios: Room Air Conditioners (RACs)

In this section, we estimate the benefit-to-cost ratio of smart RACs in various markets based on both optimistic and pessimistic sets of assumptions. Note that, unlike other appliances, for RACs we utilize the ELCAP summer load shape to estimate on-peak and off-peak consumption. We assume no RAC consumption during the non-summer months.

### 4.3.1 High-End Optimistic Results

We first present below in Table 4-13 the annual on-peak and off-peak electricity consumption of RACs based on the optimistic assumptions presented in Section 3.1.

**Table 4-13**. RAC On-Peak and Off-Peak Consumption Based on ELCAP Average Summer Day Load Shape and Optimistic Assumptions

| ELCAP (1990) Room Air Conditioner Load Shape | | | | 2010 Annual Room Air Conditioner On-Peak and Off-Peak Consumption | | |
|---|---|---|---|---|---|---|
| Load Shape: | Average Day | Summer | | | | |
| | Daily Total | On-Peak | Annual On-Peak To Total Ratio | Total Annual Consumption (2010) (kWh/yr) | Annual On-Peak Consumption (2010) (kWh/yr) | Annual Off-Peak Consumption (2010) (kWh/yr) |
| Start, Hour Ending: | 1 | 13 | | | | |
| Through Hour Ending: | 24 | 18 | | | | |
| | (kWh/day) | (kWh/day) | | | | |
| | 5.73 | 2.15 | 0.37 | 693 | 260 | 433 |

Based on the data shown in Table 4-13, high-end wholesale power production cost savings using smart RACs for peak load shifting are shown in Table 4-14 below.

**Table 4-14**. Wholesale Cost Savings from Using Smart RACs for Peak Load Shifting – Optimistic View

| | Annual Hourly Energy Market Clearing Prices | | | Annual Energy Cost (No Load Shift) | | Annual Energy Cost Savings from 100% Peak Load Shift | |
|---|---|---|---|---|---|---|---|
| | Avg. On-Peak | Avg. Off-Peak | Avg. Shift-To Hours | On-Peak | Off-Peak | On-Peak Energy Moved to "Shift To" Hours | Savings |
| Market and Year | ($/MWh) | ($/MWh) | ($/MWh) | ($/yr) | ($/yr) | (kWh/yr) | ($/yr) |
| PJM 2006 | $66.12 | $36.59 | $36.59 | $17.17 | $15.85 | 259.70 | $7.67 |
| ERCOT 2008 | $126.97 | $73.33 | $73.33 | $32.97 | $31.77 | 259.70 | $13.93 |
| NYISO 2008 | $151.26 | $93.35 | $100.09 | $39.28 | $40.45 | 259.70 | $13.29 |
| NYISO 2006 | $115.97 | $64.36 | $64.36 | $30.12 | $27.89 | 259.70 | $13.40 |
| CAISO 2008 | $109.26 | $69.76 | $69.76 | $28.38 | $30.23 | 259.70 | $10.26 |

The high-end wholesale cost savings from using smart RACs for providing spinning reserves is shown in Table 4-15 below.

**Table 4-15**. Wholesale Cost Savings from Using Smart RACs for Spinning Reserves – Optimistic View

| | Annual Hourly SR Market Clearing Prices | | | Annual Room Air Conditioner SR Market Value | | |
|---|---|---|---|---|---|---|
| | Avg. On-Peak | Avg. Off-Peak | Avg. Shift-To Hours | On Peak: From Room Air Conditioner Load After 100% Shifted | Off-Peak: From Room Air Conditioner Off-Peak Load + 100% Load shifted from Peak to 'Shift To' Hours | Total Spinning Reserve Cost Savings |
| Market and Year | ($/MWh) | ($/MWh) | ($/MWh) | ($/yr) | ($/yr) | ($/yr) |
| PJM 2006 | $4.31 | $3.54 | $3.54 | $0.00 | $2.45 | $2.45 |
| ERCOT 2008 | $36.85 | $23.76 | $23.76 | $0.00 | $16.47 | $16.47 |
| NYISO 2008 | $14.84 | $8.56 | $8.56 | $0.00 | $5.93 | $5.93 |
| NYISO 2006 | $12.40 | $5.42 | $5.42 | $0.00 | $3.76 | $3.76 |
| CAISO 2008 | $13.26 | $3.56 | $3.57 | $0.00 | $2.47 | $2.47 |

The additional 6% optimistic electricity consumption and cost savings resulting from providing energy-use feedback to customers is shown below in Table 4-16.

**Table 4-16**. Additional 6% Savings Resulting from RAC Consumption Feedback to Customers

| Market and Year | (kWh/yr) | ($/yr) |
|---|---|---|
| PJM 2006 | 42 | $1.98 |
| ERCOT 2008 | 42 | $3.88 |
| NYISO 2008 | 42 | $4.78 |
| NYISO 2006 | 42 | $3.48 |
| CAISO 2008 | 42 | $3.52 |

Finally, the overall high-end benefits (wholesale cost savings resulting from peak-load shifting, spinning reserves, consumer feedback, and their combined total) and cost (5% credit) are shown in Table 4-17 below, expressed as benefits-to-cost percentages; and the percentages of total benefits individually attributable to peak-load shifting, spinning reserves, and feedback effect are shown below in Table 4-18.

**Table 4-17**. Smart RAC Benefit (Peak Load Shift + Spinning Reserves + Feedback Effect)-to-Cost Ratio – Optimistic View

| Market and Year | Grid Operational Cost Savings (Benefits) | Cost of Additional Energy Consumption at 5% Credit | Load Shift Benefits to Cost Ratio | Spinning Reserves Benefits to Cost Ratio | Feedback Effect Benefits to Cost Ratio | Total Benefits to Cost Ratio |
|---|---|---|---|---|---|---|
| | ($/yr) | ($/yr) | (-) | (-) | (-) | (-) |
| PJM 2006 | $12.11 | $1.65 | 465% | 149% | 120% | **733%** |
| ERCOT 2008 | $34.30 | $3.24 | 430% | 509% | 120% | **1060%** |
| NYISO 2008 | $24.18 | $4.13 | 322% | 144% | 120% | **585%** |
| NYISO 2006 | $20.64 | $2.90 | 462% | 130% | 120% | **712%** |
| CAISO 2008 | $16.24 | $2.93 | 350% | 84% | 120% | **554%** |

Table 4-18. Percentage of Total RAC Benefits Attributable to Load Shift, Spinning Reserves, and Feedback Effect - Optimistic View

| Market and Year | Peak-Load Shifting | Spinning Resreves | Feedback Effect |
|---|---|---|---|
| PJM 2006 | 63% | 20% | 16% |
| ERCOT 2008 | 41% | 48% | 11% |
| NYISO 2008 | 55% | 25% | 21% |
| NYISO 2006 | 65% | 18% | 17% |
| CAISO 2008 | 63% | 15% | 22% |

Thus, as can be observed from Table 4-17, the benefit–to-cost ratios overwhelmingly exceed 100% in all markets.

### 4.3.2 Low-End Pessimistic Results

We first present below in Table 4-19 the annual on-peak and off-peak electricity consumption based on the pessimistic assumptions presented in Section 3.1.

**Table 4-19**. RAC On-Peak and Off-Peak Consumption Based on ELCAP Average Summer Day Load Shape and Pessimistic Assumptions

| ELCAP (1990) Room Air Conditioner Load Shape | | | | 2010 Annual Room Air Conditioner On-Peak and Off-Peak Consumption | | |
|---|---|---|---|---|---|---|
| Load Shape: | Average Day | Summer | | Total Annual Consumption (2010) (kWh/yr) | Annual On-Peak Consumption (2010) (kWh/yr) | Annual Off-Peak Consumption (2010) (kWh/yr) |
| | Daily Total | On-Peak | Annual On-Peak To Total Ratio | | | |
| Start, Hour Ending: | 1 | 14 | | | | |
| Through Hour Ending: | 24 | 17 | | | | |
| | (kWh/day) | (kWh/day) | | | | |
| | 5.73 | 1.43 | 0.25 | 693 | 173 | 520 |

Based on the data shown in Table 4-19, high-end wholesale power production cost savings using smart CDs for peak load shifting are shown below in Table 4-20.

**Table 4-20**. Wholesale Cost Savings from Using Smart RACs for Peak Load Shifting – Pessimistic View

| | Annual Hourly Energy Market Clearing Prices | | | Annual Energy Cost (No Load Shift) | | Annual Energy Cost Savings from 6% Peak Load Shift | |
|---|---|---|---|---|---|---|---|
| | Avg. On-Peak | Avg. Off-Peak | Avg. Shift-To Hours | On-Peak | Off-Peak | On-Peak Energy Moved to "Shift To" Hours | Savings |
| Market and Year | ($/MWh) | ($/MWh) | ($/MWh) | ($/yr) | ($/yr) | (kWh/yr) | ($/yr) |
| PJM 2006 | $74.45 | $41.60 | $41.59 | $12.91 | $21.61 | 10.84 | $0.36 |
| ERCOT 2008 | $136.50 | $80.23 | $80.23 | $23.67 | $41.69 | 10.84 | $0.61 |
| NYISO 2008 | $164.45 | $104.01 | $104.01 | $28.52 | $54.04 | 10.84 | $0.66 |
| NYISO 2006 | $142.54 | $73.03 | $73.03 | $24.72 | $37.94 | 10.84 | $0.75 |
| CAISO 2008 | $123.28 | $73.79 | $73.79 | $21.38 | $38.34 | 10.84 | $0.54 |

The low-end wholesale cost savings from using smart RACs for providing spinning reserves is shown in Table 4-21 below.

Table 4-21. Wholesale Cost Savings from Using Smart RACs for Spinning Reserves – Pessimistic View

| | Annual Hourly SR Market Clearing Prices | | | Annual Room Air Conditioner SR Market Value | | |
|---|---|---|---|---|---|---|
| | Avg. On-Peak | Avg. Off-Peak | Avg. Shift-To Hours | On Peak: From Room Air Conditioner Load After 6% Shifted | Off-Peak: From Room Air Conditioner Off-Peak Load + 6% Load shifted from Peak to 'Shift To' Hours | Total Spinning Reserve Cost Savings |
| Market and Year | ($/MWh) | ($/MWh) | ($/MWh) | ($/yr) | ($/yr) | ($/yr) |
| PJM 2006 | $4.00 | $3.33 | $3.33 | $0.23 | $0.64 | $0.87 |
| ERCOT 2008 | $37.42 | $25.57 | $25.58 | $2.19 | $4.88 | $7.07 |
| NYISO 2008 | $14.38 | $9.16 | $9.16 | $0.84 | $1.75 | $2.59 |
| NYISO 2006 | $16.02 | $7.62 | $7.62 | $0.94 | $1.46 | $2.39 |
| CAISO 2008 | $14.90 | $4.29 | $4.29 | $0.87 | $0.82 | $1.69 |

The additional 3% pessimistic electricity consumption and cost savings resulting from providing energy-use feedback to customers is shown below in Table 4-22.

**Table 4-22**. Additional 3% Savings Resulting from RAC Consumption Feedback to Customers

| Market and Year | (kWh/yr) | ($/yr) |
|---|---|---|
| PJM 2006 | 21 | $1.04 |
| ERCOT 2008 | 21 | $1.96 |
| NYISO 2008 | 21 | $2.34 |
| NYISO 2006 | 21 | $1.88 |
| CAISO 2008 | 21 | $1.79 |

Finally the low-end benefits (wholesale cost savings resulting from peak-load shifting, spinning reserves, consumer feedback, and their combined total) and cost (5% credit) are shown below in Table 4-23 expressed as benefits-to-cost percentages; and the percentages of total benefits individually attributable to peak-load shifting, spinning reserves, and feedback effect are shown below in Table 4-24.

**Table 4-23**. Smart RAC Benefit (Peak Load Shift + Spinning Reserves + Feedback Effect)-to-Cost Ratio – Pessimistic View

| | Grid Operational Cost Savings (Benefits) | Cost of Additional Energy Consumption at 5% Credit | Load Shift Benefits to Cost Ratio | Spinning Reserves Benefits to Cost Ratio | Feedback Effect Benefits to Cost Ratio | Total Benefits to Cost Ratio |
|---|---|---|---|---|---|---|
| Market and Year | ($/yr) | ($/yr) | (-) | (-) | (-) | (-) |
| PJM 2006 | $2.26 | $1.73 | 21% | 50% | 60% | **131%** |
| ERCOT 2008 | $9.64 | $3.27 | 19% | 216% | 60% | **295%** |
| NYISO 2008 | $5.72 | $4.13 | 16% | 63% | 60% | **139%** |
| NYISO 2006 | $5.03 | $3.13 | 24% | 76% | 60% | **160%** |
| CAISO 2008 | $4.02 | $2.99 | 18% | 57% | 60% | **135%** |

Table 4-24. Percentage of Total RAC Benefits Attributable to Load Shift, Spinning Reserves, and Feedback Effect - Pessimistic View

| Market and Year | Peak-Load Shifting | Spinning Resreves | Feedback Effect |
|---|---|---|---|
| PJM 2006 | 16% | 38% | 46% |
| ERCOT 2008 | 6% | 73% | 20% |
| NYISO 2008 | 11% | 45% | 43% |
| NYISO 2006 | 15% | 48% | 37% |
| CAISO 2008 | 13% | 42% | 45% |

Thus, as can be observed from Table 4-23, the benefit–to-cost ratios exceed 100% even for the pessimistic set of assumptions in all markets.

## 4.4 Benefit-to-Cost Ratios: Smart Refrigerators

In this section, we estimate the benefit-to-cost ratio of smart refrigerators in various markets based on both optimistic and pessimistic sets of assumptions.

### 4.4.1 High-End Optimistic Results

We first present below in Table 4.21 the refrigerator annual on-peak and off-peak electricity consumption, including the defrost and ice-making splits, based on the optimistic assumptions presented in Section 3.1.

**Table 4-25**. Refrigerator On-Peak and Off-Peak Consumption Based on ELCAP Average Annual Day Load Shape and Optimistic Assumptions

| ELCAP (1990) Refrigerator Load Shape | | | | | 2010 Annual Refrigerator On-Peak and Off-Peak Consumption | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Load Shape: | Average Day | Annual | | | | | | | | | | | |
| | Daily Total | On-Peak | Avg. No. of On-Peak Days/Year | Annual On-Peak To Total Ratio | Total Refrigerator Annual Consumption | Defrost Annual Consumption | Ice-Making Annual Consumption | Annual Refrigerator On-Peak Consumption | Annual Refrigerator Off-Peak Consumption | Annual Defrost On-Peak Consumption | Annual Defrost Off-Peak Consumption | Annual Ice-Making On-Peak Consumption | Annual Ice-Making Off-Peak Consumption |
| Start, Hour Ending: | 1 | 13 | | | | | | | | | | | |
| Through Hour Ending: | 24 | 18 | | | | | | | | | | | |
| | (kWh/day) | (kWh/day) | | | (kWh/yr) | (kWh/yr) | (kWh/yr) | (kWh/yr) | (kWh/yr) | (kWh/yr) | (kWh/yr) | (kWh/yr) | (kWh/yr) |
| | 4.12 | 1.07 | 365 | 0.26 | 450 | 50 | 84 | 117 | 333 | 13 | 37 | 22 | 62 |

Based on the data shown in Table 4-25, high-end wholesale power production cost savings using smart refrigerators for peak-load shifting are shown in Table 4-26 below.

Table 4-26. Wholesale Cost Savings from Using Smart Refrigerators for Peak Load Shifting – Optimistic View

| | Annual Hourly Energy Market Clearing Prices | | | Annual Energy Cost (No Load Shift) | | Annual Energy Cost Savings (from 100% Defrost Load Shift) | | Annual Energy Cost Savings (from 100% Ice-Making Load Shift) | | Annual Energy Cost Savings (Total) | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Avg. On-Peak | Avg. Off-Peak | Avg. Shift-To Hours | On-Peak | Off-Peak | On-Peak Energy Moved to "Shift To" Hours | Savings | On-Peak Energy Moved to "Shift To" Hours | Savings | On-Peak Energy Moved to "Shift To" Hours | Savings |
| Market and Year | ($/MWh) | ($/MWh) | ($/MWh) | ($/yr) | ($/yr) | (kWh/yr) | ($/yr) | (kWh/yr) | ($/yr) | (kWh/yr) | ($/yr) |
| PJM 2006 | $50.64 | $39.44 | $39.44 | $5.94 | $13.12 | 12.90 | $0.14 | 21.90 | $0.25 | 34.81 | 0.39 |
| ERCOT 2008 | $105.56 | $67.09 | $67.09 | $12.38 | $22.32 | 12.90 | $0.50 | 21.90 | $0.84 | 34.81 | 1.34 |
| NYISO 2008 | $115.97 | $92.25 | $92.27 | $13.60 | $30.69 | 12.90 | $0.31 | 21.90 | $0.52 | 34.81 | 0.83 |
| NYISO 2006 | $85.05 | $67.44 | $67.41 | $9.98 | $22.44 | 12.90 | $0.23 | 21.90 | $0.39 | 34.81 | 0.61 |
| CAISO 2008 | $82.11 | $65.01 | $65.02 | $9.63 | $21.63 | 12.90 | $0.22 | 21.90 | $0.37 | 34.81 | 0.60 |

The high-end wholesale cost savings from using smart refrigerators for providing spinning reserves is shown in Table 4-27 below.

**Table 4-27**. Wholesale Cost Savings from Using Smart Refrigerators for Spinning Reserves - Optimistic View

| | Annual Hourly Average Market Clearing Prices: SR | | | Annual Refrigerator SR Market Value | | |
|---|---|---|---|---|---|---|
| | Avg. On-Peak | Avg. Off-Peak | Avg. Shift-To Hours | On-Peak: From Refrigerator Load After 100% Defrost and 100% Ice-Making Shifted | Off-Peak: From Refrigerator Off-Peak Load + 100% Defrost and 100% Ice-Making Load shifted from Peak to 'Shift To' | Total Spinning Reserve Cost Savings |
| Market and Year | ($/MWh) | ($/MWh) | ($/MWh) | ($/yr) | ($/yr) | ($/yr) |
| PJM 2006 | $7.29 | $8.08 | $8.08 | $0.60 | $2.97 | $3.57 |
| ERCOT 2008 | $36.85 | $23.76 | $23.76 | $3.04 | $8.73 | $11.77 |
| NYISO 2008 | $14.84 | $8.56 | $8.56 | $1.22 | $3.15 | $4.37 |
| NYISO 2006 | $12.40 | $5.42 | $5.42 | $1.02 | $1.99 | $3.01 |
| CAISO 2008 | $13.26 | $3.56 | $3.57 | $1.09 | $1.31 | $2.40 |

The additional 6% optimistic electricity consumption and cost savings resulting from providing energy-use feedback to customers is shown below in Table 4-28.

**Table 4-28**. Additional 6% Savings Resulting from CD Consumption Feedback to Customers

| Market and Year | (kWh/yr) | ($/yr) |
|---|---|---|
| PJM 2006 | 27 | $1.14 |
| ERCOT 2008 | 27 | $2.08 |
| NYISO 2008 | 27 | $2.66 |
| NYISO 2006 | 27 | $1.94 |
| CAISO 2008 | 27 | $1.88 |

Finally the high-end benefits (wholesale cost saving resulting from peak-load shifting, spinning reserves, consumer feedback, and their combined total) and cost are shown below in Table 4-29 expressed as benefits-to-cost percentages; and the percentages of total benefits individually attributable to peak-load shifting, spinning reserves, and feedback effect are shown below in Table 4-30.

**Table 4-29**. Smart Refrigerator Benefit (Peak Load Shift + Spinning Reserves + Feedback Effect)-to-Cost Ratio – Optimistic View

| | Grid Operational Cost Savings (Benefits) | Cost of Additional Energy Consumption at 5% Credit | Load Shift Benefits to Cost Ratio | Spinning Reserves Benefits to Cost Ratio | Feedback Effect Benefits to Cost Ratio | Total Benefits to Cost Ratio |
|---|---|---|---|---|---|---|
| Market and Year | ($/yr) | ($/yr) | (-) | (-) | (-) | (-) |
| PJM 2006 | $5.10 | $0.95 | 41% | 375% | 120% | **536%** |
| ERCOT 2008 | $15.19 | $1.73 | 77% | 680% | 120% | **877%** |
| NYISO 2008 | $7.85 | $2.21 | 37% | 197% | 120% | **355%** |
| NYISO 2006 | $5.57 | $1.62 | 38% | 186% | 120% | **344%** |
| CAISO 2008 | $4.87 | $1.56 | 38% | 154% | 120% | **312%** |

Table 4-30. Percentage of Total Smart Refrigerator Benefits Attributable to Load Shift, Spinning Reserves, and Feedback Effect - Optimistic View

| Market and Year | Peak-Load Shifting | Spinning Resreves | Feedback Effect |
|---|---|---|---|
| PJM 2006 | 8% | 70% | 22% |
| ERCOT 2008 | 9% | 78% | 14% |
| NYISO 2008 | 11% | 56% | 34% |
| NYISO 2006 | 11% | 54% | 35% |
| CAISO 2008 | 12% | 49% | 39% |

Thus, as can be observed from Table 4-29, the benefit–to-cost ratios overwhelmingly exceed 100% in all markets.

### 4.4.2 Low-End Pessimistic Results

We first present below in Table 4-31 the annual on-peak and off-peak electricity consumption based on the pessimistic assumptions presented in Section 3.1.

**Table 4-31**. Refrigerator On-Peak and Off-Peak Consumption Based on ELCAP Average Annual Day Load Shape and Pessimistic Assumptions

| ELCAP (1990) Refrigerator Load Shape | | | | | 2010 Annual Refrigerator On-Peak and Off-Peak Consumption | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Load Shape: | Average Day | Annual | | | | | | | | | | | |
| Start, Hour Ending: / Through Hour Ending: | Daily Total 1 / 24 (kWh/day) | On-Peak 14 / 17 (kWh/day) | Avg. No. of On-Peak Days/Year | Annual On-Peak To Total Ratio | Total Refrigerator Annual Consumption (kWh/yr) | Defrost Annual Consumption (kWh/yr) | Ice-Making Annual Consumption (kWh/yr) | Annual Refrigerator On-Peak Consumption (kWh/yr) | Annual Refrigerator Off-Peak Consumption (kWh/yr) | Annual Defrost On-Peak Consumption (kWh/yr) | Annual Defrost Off-Peak Consumption (kWh/yr) | Annual Ice-Making On-Peak Consumption (kWh/yr) | Annual Ice-Making Off-Peak Consumption (kWh/yr) |
| | 4.12 | 0.70 | 261 | 0.12 | 450 | 50 | 84 | 55 | 395 | 6 | 43 | 10 | 74 |

Based on the data shown in Table 4-31, high-end wholesale power production cost savings using smart refrigerators for peak load shifting are shown below in Table 4-32.

**Table 4-32**. Wholesale Cost Savings from Using Smart Refrigerators for Peak Load Shifting – Pessimistic View

| | Annual Hourly Energy Market Clearing Prices | | | Annual Energy Cost (No Load Shift) | | Annual Energy Cost Savings (from 45%Defrost Load Shift) | | Annual Energy Cost Savings (from 27%Ice-Making Load Shift) | | Annual Energy Cost Savings (Total) | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Market and Year | Avg. On-Peak ($/MWh) | Avg. Off-Peak ($/MWh) | Avg. Shift-To Hours ($/MWh) | On-Peak ($/yr) | Off-Peak ($/yr) | On-Peak Energy Moved to "Shift To" Hours (kWh/yr) | Savings ($/yr) | On-Peak Energy Moved to "Shift To" Hours (kWh/yr) | Savings ($/yr) | On-Peak Energy Moved to "Shift To" Hours (kWh/yr) | Savings ($/yr) |
| PJM 2006 | $55.55 | $40.45 | $42.90 | $3.06 | $15.98 | 2.72 | $0.03 | 2.77 | $0.04 | 5.50 | 0.07 |
| ERCOT 2008 | $119.27 | $70.95 | $73.03 | $6.56 | $28.02 | 2.72 | $0.13 | 2.77 | $0.13 | 5.50 | 0.25 |
| NYISO 2008 | $120.56 | $95.16 | $94.83 | $6.63 | $37.59 | 2.72 | $0.07 | 2.77 | $0.07 | 5.50 | 0.14 |
| NYISO 2006 | $93.91 | $68.87 | $72.50 | $5.17 | $27.20 | 2.72 | $0.06 | 2.77 | $0.06 | 5.50 | 0.12 |
| CAISO 2008 | $88.25 | $66.72 | $68.67 | $4.85 | $26.35 | 2.72 | $0.05 | 2.77 | $0.05 | 5.50 | 0.11 |

The low-end wholesale cost savings from using smart refrigerators for providing spinning reserves is shown in Table 4-33 below.

**Table 4-33**. Wholesale Cost Savings from Using Smart Refrigerators for Spinning Reserves – Pessimistic View

| | Annual Hourly Average Market Clearing Prices: SR | | | Annual Refrigerator SR Market Value | | |
|---|---|---|---|---|---|---|
| | Avg. On-Peak | Avg. Off-Peak | Avg. Shift-To Hours | On-Peak: From Refrigerator Load After 45% Defrost and 27% Ice- | Off-Peak: From Refrigerator Off-Peak Load + 45% Defrost and 27% Ice-Making Load | Total Spinning Reserve Cost Savings |
| Market and Year | ($/MWh) | ($/MWh) | ($/MWh) | ($/yr) | ($/yr) | ($/yr) |
| PJM 2006 | $7.30 | $8.29 | $8.29 | $0.08 | $0.75 | $0.83 |
| ERCOT 2008 | $37.42 | $25.57 | $25.58 | $0.42 | $2.30 | $2.72 |
| NYISO 2008 | $14.38 | $9.16 | $9.16 | $0.16 | $0.83 | $0.99 |
| NYISO 2006 | $16.02 | $7.62 | $7.62 | $0.18 | $0.69 | $0.87 |
| CAISO 2008 | $14.90 | $4.29 | $4.29 | $0.17 | $0.39 | $0.55 |

The additional 3% pessimistic electricity consumption and cost savings resulting from providing energy-use feedback to customers is shown below in Table 4-34.

**Table 4-34**. Additional 3% Savings Resulting from Refrigerator Consumption Feedback to Customers

| Market and Year | (kWh/yr) | ($/yr) |
|---|---|---|
| PJM 2006 | 14 | $0.60 |
| ERCOT 2008 | 14 | $1.06 |
| NYISO 2008 | 14 | $1.32 |
| NYISO 2006 | 14 | $1.01 |
| CAISO 2008 | 14 | $0.96 |

Finally, the low-end benefits (wholesale cost saving resulting from peak-load shifting, spinning reserves, consumer feedback, and their combined total) and cost (5% credit) are shown below in Table 4-35, expressed as benefits-to-cost percentages; and the percentages of total benefits individually attributable to peak-load shifting, spinning reserves, and feedback effect are shown below in Table 4-36.

**Table 4-35**. Smart Refrigerator Benefits (Peak Load Shift + Spinning Reserves + Feedback Effect)-to-Cost Ratio – Pessimistic View

| | Grid Operational Cost Savings (Benefits) | Cost of Additional Energy Consumption at 5% Credit | Load Shift Benefits to Cost Ratio | Spinning Reserves Benefits to Cost Ratio | Feedback Effect Benefits to Cost Ratio | Total Benefits to Cost Ratio |
|---|---|---|---|---|---|---|
| Market and Year | ($/yr) | ($/yr) | (-) | (-) | (-) | (-) |
| PJM 2006 | $1.50 | $1.00 | 7% | 83% | 60% | **150%** |
| ERCOT 2008 | $4.03 | $1.77 | 14% | 154% | 60% | **228%** |
| NYISO 2008 | $2.45 | $2.20 | 6% | 45% | 60% | **111%** |
| NYISO 2006 | $2.00 | $1.69 | 7% | 51% | 60% | **118%** |
| CAISO 2008 | $1.62 | $1.60 | 7% | 35% | 60% | **101%** |

Table 4-36. Percentage of Total Smart Refrigerator Benefits Attributable to Load Shift, Spinning Reserves, and Feedback Effect - Pessimistic View

| Market and Year | Peak-Load Shifting | Spinning Resreves | Feedback Effect |
|---|---|---|---|
| PJM 2006 | 5% | 55% | 40% |
| ERCOT 2008 | 6% | 67% | 26% |
| NYISO 2008 | 6% | 40% | 54% |
| NYISO 2006 | 6% | 43% | 51% |
| CAISO 2008 | 7% | 34% | 59% |

Thus, as can be observed from Table 4-35, the benefit–to-cost ratios exceed 100% even for the pessimistic set of assumptions in all markets.

## 4.5 Benefit-to-Cost Ratios: Smart Freezers

In this section, we estimate the benefit-to-cost ratio of smart freezers in various markets based on both optimistic and pessimistic sets of assumptions.

### 4.5.1 High-End Optimistic Results

We first present below in Table 4-37 the refrigerator annual on-peak and off-peak electricity consumption, including the defrost and ice-making splits, based on the optimistic assumptions presented in Section 3.1.

**Table 4-37**. Freezer On-Peak and Off-Peak Consumption Based on ELCAP Average Annual Day Load Shape and Optimistic Assumptions

| ELCAP (1990) Freezer Load Shape | | | | | 2010 Annual Freezer On-Peak and Off-Peak Consumption | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Load Shape: | Average Day | Annual | Avg. No. of On-Peak Days/Year | Annual On-Peak To Total Ratio | Total Freezer Annual Consumption | Defrost Annual Consumption | Ice-Making Annual Consumption | Annual Freezer On-Peak Consumption | Annual Freezer Off-Peak Consumption | Annual Defrost On-Peak Consumption | Annual Defrost Off-Peak Consumption | Annual Ice-Making On-Peak Consumption | Annual Ice-Making Off-Peak Consumption |
| | Daily Total | On-Peak | | | | | | | | | | | |
| Start, Hour Ending: | 1 | 13 | | | | | | | | | | | |
| Through Hour Ending: | 24 | 18 | | | | | | | | | | | |
| | (kWh/day) | (kWh/day) | | | (kWh/yr) | (kWh/yr) | (kWh/yr) | (kWh/yr) | (kWh/yr) | (kWh/yr) | (kWh/yr) | (kWh/yr) | (kWh/yr) |
| | 4.21 | 1.10 | 365 | 0.26 | 423 | 51 | 85 | 111 | 312 | 13 | 37 | 22 | 62 |

Based on the data shown in Table 4-37, high-end wholesale power production cost savings using smart freezers for peak load shifting are shown in Table 4-38 below.

**Table 4-38**. Wholesale Cost Savings from Using Smart Freezers for Peak Load Shifting – Optimistic View

| | Annual Hourly Energy Market Clearing Prices | | | Annual Energy Cost (No Load Shift) | | Annual Energy Cost Savings (from 100% Defrost Load Shift) | | Annual Energy Cost Savings (from 100% Icemaking Load Shift) | | Annual Energy Cost Savings (Total) | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Avg. On-Peak | Avg. Off-Peak | Avg. Shift-To Hours | On-Peak | Off-Peak | On-Peak Energy Moved to "Shift To" Hours | Savings | On-Peak Energy Moved to "Shift To" Hours | Savings | On-Peak Energy Moved to "Shift To" Hours | Savings |
| Market and Year | ($/MWh) | ($/MWh) | ($/MWh) | ($/yr) | ($/yr) | (kWh/yr) | ($/yr) | (kWh/yr) | ($/yr) | (kWh/yr) | ($/yr) |
| PJM 2006 | $50.64 | $39.45 | $39.44 | $5.94 | $13.12 | 12.90 | $0.14 | 21.90 | $0.25 | 34.81 | 0.39 |
| ERCOT 2008 | $105.36 | $66.99 | $66.98 | $12.36 | $22.29 | 12.90 | $0.50 | 21.90 | $0.84 | 34.81 | 1.34 |
| NYISO 2008 | $115.96 | $92.22 | $92.23 | $13.60 | $30.68 | 12.90 | $0.31 | 21.90 | $0.52 | 34.81 | 0.83 |
| NYISO 2006 | $85.05 | $67.44 | $67.41 | $9.98 | $22.44 | 12.90 | $0.23 | 21.90 | $0.39 | 34.81 | 0.61 |
| CAISO 2008 | $81.99 | $64.94 | $64.95 | $9.62 | $21.61 | 12.90 | $0.22 | 21.90 | $0.37 | 34.81 | 0.59 |

The high-end wholesale cost savings from using smart freezers for providing spinning reserves is shown in Table 4-39 below.

**Table 4-39**. Wholesale Cost Savings from Using Smart Freezers for Spinning Reserves – Optimistic View

| | Annual Hourly Average Market Clearing Prices: SR | | | Annual Refrigerator SR Market Value | | |
|---|---|---|---|---|---|---|
| | Avg. On-Peak | Avg. Off-Peak | Avg. Shift-To Hours | On-Peak: From Refrigerator Load After 100% Defrost and 100% Ice- | Off-Peak: From Refrigerator Off-Peak Load + 100% Defrost and 100% Ice-Making Load | Total Spinning Reserve Cost Savings |
| Market and Year | ($/MWh) | ($/MWh) | ($/MWh) | ($/yr) | ($/yr) | ($/yr) |
| PJM 2006 | $7.29 | $8.08 | $8.08 | $0.60 | $2.97 | $3.57 |
| ERCOT 2008 | $36.80 | $23.79 | $23.79 | $3.04 | $8.74 | $11.78 |
| NYISO 2008 | $14.84 | $8.56 | $8.56 | $1.22 | $3.15 | $4.37 |
| NYISO 2006 | $12.40 | $5.42 | $5.42 | $1.02 | $1.99 | $3.02 |
| CAISO 2008 | $13.23 | $3.56 | $3.56 | $1.09 | $1.31 | $2.40 |

The additional 6% optimistic electricity consumption and cost savings resulting from providing energy-use feedback to customers is shown below in Table 4-40.

**Table 4-40**. Additional 6% Savings Resulting from CD Consumption Feedback to Customers

| Market and Year | (kWh/yr) | ($/yr) |
|---|---|---|
| PJM 2006 | 27 | $1.14 |
| ERCOT 2008 | 27 | $2.08 |
| NYISO 2008 | 27 | $2.66 |
| NYISO 2006 | 27 | $1.94 |
| CAISO 2008 | 27 | $1.87 |

Finally, the high-end benefits (wholesale cost saving resulting from peak-load shifting, spinning reserves, consumer feedback, and their combined total) and cost (5% credit) are shown below in Table 4-41, expressed as benefits-to-cost percentages; and the percentages of total benefits individually attributable to peak-load shifting, spinning reserves, and feedback effect are shown below in Table 4-42.

**Table 4-41**. Smart Freezer Benefit (Peak Load Shift + Spinning Reserves + Feedback Effect)-to-Cost Ratio – Optimistic View

| Market and Year | Grid Operational Cost Savings (Benefits) ($/yr) | Cost of Additional Energy Consumption at 5% Credit ($/yr) | Load Shift Benefits to Cost Ratio (-) | Spinning Reserves Benefits to Cost Ratio (-) | Feedback Effect Benefits to Cost Ratio (-) | Total Benefits to Cost Ratio (-) |
|---|---|---|---|---|---|---|
| PJM 2006 | $5.10 | $0.95 | 41% | 375% | 120% | **536%** |
| ERCOT 2008 | $15.19 | $1.73 | 77% | 680% | 120% | **877%** |
| NYISO 2008 | $7.85 | $2.21 | 37% | 197% | 120% | **355%** |
| NYISO 2006 | $5.57 | $1.62 | 38% | 186% | 120% | **344%** |
| CAISO 2008 | $4.87 | $1.56 | 38% | 154% | 120% | **312%** |

Table 4-42. Percentage of Total Smart Freezer Benefits Attributable to Load Shift, Spinning Reserves, and Feedback Effect - Optimistic View

| Market and Year | Peak-Load Shifting | Spinning Resreves | Feedback Effect |
|---|---|---|---|
| PJM 2006 | 8% | 70% | 22% |
| ERCOT 2008 | 9% | 78% | 14% |
| NYISO 2008 | 11% | 56% | 34% |
| NYISO 2006 | 11% | 54% | 35% |
| CAISO 2008 | 12% | 49% | 39% |

Thus, as can be observed from Table 4-41, the benefit–to-cost ratios overwhelmingly exceed 100% in all markets.

### 4.5.2 Low-End Pessimistic Results

We first present below in Table 4-43, the annual on-peak and off-peak electricity consumption based on the pessimistic assumptions presented in Section 3.1.

**Table 4-43**. Freezer On-Peak and Off-Peak Consumption Based on ELCAP Average Annual Day Load Shape and Pessimistic Assumptions

| ELCAP (1990) Refrigerator Load Shape | | | | | 2010 Annual Refrigerator On-Peak and Off-Peak Consumption | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Load Shape: | Average Day | Annual | | | Total Refrigerator Annual Consumption | Defrost Annual Consumption | Ice-Making Annual Consumption | Annual Refrigerator On-Peak Consumption | Annual Refrigerator Off-Peak Consumption | Annual Defrost On-Peak Consumption | Annual Defrost Off-Peak Consumption | Annual Ice-Making On-Peak Consumption | Annual Ice-Making Off-Peak Consumption |
| | Daily Total | On-Peak | Avg. No. of On-Peak Days/Year | Annual On-Peak To Total Ratio | | | | | | | | | |
| Start, Hour Ending: | 1 | 14 | | | | | | | | | | | |
| Through Hour Ending: | 24 | 17 | | | | | | | | | | | |
| | (kWh/day) | (kWh/day) | | | (kWh/yr) | (kWh/yr) | (kWh/yr) | (kWh/yr) | (kWh/yr) | (kWh/yr) | (kWh/yr) | (kWh/yr) | (kWh/yr) |
| | 4.12 | 0.70 | 261 | 0.12 | 450 | 50 | 84 | 55 | 395 | 6 | 43 | 10 | 74 |

Based on the data shown in Table 4-43, high-end wholesale power production cost savings using smart freezers for peak load shifting are shown below in Table 4-44.

**Table 4-44**. Wholesale Cost Savings from Using Smart Freezers for Peak Load Shifting - Pessimistic View

| | Annual Hourly Energy Market Clearing Prices | | | Annual Energy Cost (No Load Shift) | | Annual Energy Cost Savings (from 45% Defrost Load Shift) | | Annual Energy Cost Savings (from 45% Icemaking Load Shift) | | Annual Energy Cost Savings (Total) | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Avg. On-Peak | Avg. Off-Peak | Avg. Shift-To Hours | On-Peak | Off-Peak | On-Peak Energy Moved to "Shift To" Hours | Savings | On-Peak Energy Moved to "Shift To" Hours | Savings | On-Peak Energy Moved to "Shift To" Hours | Savings |
| Market and Year | ($/MWh) | ($/MWh) | ($/MWh) | ($/yr) | ($/yr) | (kWh/yr) | ($/yr) | (kWh/yr) | ($/yr) | (kWh/yr) | ($/yr) |
| PJM 2006 | $55.55 | $42.90 | $42.89 | $2.92 | $15.89 | 2.84 | $0.04 | 2.84 | $0.04 | 5.68 | 0.07 |
| ERCOT 2008 | $118.93 | $72.86 | $72.86 | $6.26 | $26.99 | 2.84 | $0.13 | 2.84 | $0.13 | 5.68 | 0.26 |
| NYISO 2008 | $120.41 | $94.80 | $94.81 | $6.34 | $35.11 | 2.84 | $0.07 | 2.84 | $0.07 | 5.68 | 0.15 |
| NYISO 2006 | $93.91 | $72.50 | $72.50 | $4.94 | $26.85 | 2.84 | $0.06 | 2.84 | $0.06 | 5.68 | 0.12 |
| CAISO 2008 | $88.03 | $68.56 | $68.56 | $4.63 | $25.39 | 2.84 | $0.06 | 2.84 | $0.06 | 5.68 | 0.11 |

The low-end wholesale cost savings from using smart freezers for providing spinning reserves is shown in

Table 4-45 below.

Table 4-45**.** Wholesale Cost Savings from Using Smart Freezers for Spinning Reserves - Pessimistic View

| | Annual Hourly Average Market Clearing Prices: SR | | | Annual Freezer SR Market Value | | |
|---|---|---|---|---|---|---|
| | Avg. On-Peak | Avg. Off-Peak | Avg. Shift-To Hours | On-Peak: From Freezer Load After 45% Defrost and 27% Ice-Making Shifted | Off-Peak: From Freezer Off-Peak Load + 45% Defrost and 27% Ice-Making Load shifted from Peak to 'Shift To' Hours | Total Spinning Reserve Cost Savings |
| Market and Year | ($/MWh) | ($/MWh) | ($/MWh) | ($/yr) | ($/yr) | ($/yr) |
| PJM 2006 | $7.30 | $8.29 | $8.29 | $0.08 | $0.70 | $0.78 |
| ERCOT 2008 | $37.42 | $25.57 | $25.58 | $0.40 | $2.16 | $2.56 |
| NYISO 2008 | $14.38 | $9.16 | $9.16 | $0.15 | $0.77 | $0.93 |
| NYISO 2006 | $16.02 | $7.62 | $7.62 | $0.17 | $0.64 | $0.81 |
| CAISO 2008 | $14.90 | $4.29 | $4.29 | $0.16 | $0.36 | $0.52 |

The additional 3% pessimistic electricity consumption and cost savings resulting from providing energy-use feedback to customers is shown below in Table 4-46.

**Table 4-46**. Additional 3% Savings Resulting from Freezer Consumption Feedback to Customers

| Market and Year | (kWh/yr) | ($/yr) |
|---|---|---|
| PJM 2006 | 13 | $0.56 |
| ERCOT 2008 | 13 | $1.00 |
| NYISO 2008 | 13 | $1.24 |
| NYISO 2006 | 13 | $0.95 |
| CAISO 2008 | 13 | $0.90 |

Finally, the low-end benefits (wholesale cost saving resulting from peak-load shifting, spinning reserves, consumer feedback, and their combined total) and costs (5% credit) are shown below in Table 4-47, expressed as benefits-to-cost percentages; and the percentages of total benefits individually attributable to peak-load shifting, spinning reserves, and feedback effect are shown below in Table 4-48.

**Table 4-47**. Smart Freezer Benefits (Peak Load Shift + Spinning Reserves + Feedback Effect)-to-Cost Ratio – Pessimistic View

| | Grid Operational Cost Savings (Benefits) | Cost of Additional Energy Consumption at 5% Credit | Load Shift Benefits to Cost Ratio | Spinning Reserves Benefits to Cost Ratio | Feedback Effect Benefits to Cost Ratio | Total Benefits to Cost Ratio |
|---|---|---|---|---|---|---|
| **Market and Year** | **($/yr)** | **($/yr)** | **(-)** | **(-)** | **(-)** | **(-)** |
| PJM 2006 | $1.42 | $0.94 | 8% | 83% | 60% | **150%** |
| ERCOT 2008 | $3.82 | $1.66 | 16% | 154% | 60% | **230%** |
| NYISO 2008 | $2.32 | $2.07 | 7% | 45% | 60% | **112%** |
| NYISO 2006 | $1.89 | $1.59 | 8% | 51% | 60% | **119%** |
| CAISO 2008 | $1.53 | $1.50 | 7% | 35% | 60% | **102%** |

Table 4-48. Percentage of Total Smart Freezer Benefits Attributable to Load Shift, Spinning Reserves, and Feedback Effect - Pessimistic View

| Market and Year | Peak-Load Shifting | Spinning Resreves | Feedback Effect |
|---|---|---|---|
| PJM 2006 | 5% | 55% | 40% |
| ERCOT 2008 | 7% | 67% | 26% |
| NYISO 2008 | 6% | 40% | 54% |
| NYISO 2006 | 6% | 43% | 50% |
| CAISO 2008 | 7% | 34% | 59% |

Thus, as can be observed from Table 4-47, the benefits to cost ratios exceed 100% even for the pessimistic set of assumptions in all markets.

## 4.6 Benefit-to-Cost Ratios: Smart Clothes Washers (CWs)

In this section, we estimate the benefit-to-cost ratio of smart CWs in various markets based on both optimistic and pessimistic sets of assumptions.

### 4.6.1 High-End Optimistic Results

We first present below in Table 4-49 the CW annual on-peak and off-peak electricity consumption, including the CW machine and CW hot water splits, based on the optimistic assumptions presented in Section 3.1.

**Table 4-49**. CW On-Peak and Off-Peak Consumption Based on ELCAP Average Annual Day Load Shape and Optimistic Assumptions

| ELCAP (1990) Clothes Washer Load Shape | | | | | 2010 Annual Clothes Washer On-Peak and Off-Peak Consumption | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Load Shape: | Average Day Daily Total | Annual On-Peak | Avg. No. of On-Peak Days/Year | Annual On-Peak To Total Ratio | Total Annual Consumption (Machine + Hot Water) | Total Annual Consumption (Machine Only) | Total Annual Consumption (Hot Water Only) | Annual On-Peak Consumption (Machine Only) | Annual Off-Peak Consumption (Machine Only) | Annual On-Peak Consumption (Hot Water Only) | Annual Off-Peak Consumption (Hot Water Only) |
| Start, Hour Ending: | 1 | 13 | | | | | | | | | |
| Through Hour Ending: | 24 | 18 | | | | | | | | | |
| | (kWh/day) | (kWh/day) | | | (kWh/yr) | (kWh/yr) | (kWh/yr) | (kWh/yr) | (kWh/yr) | (kWh/yr) | (kWh/yr) |
| | 0.29 | 0.10 | 365 | 0.34 | 209 | 105 | 105 | 35 | 69 | 35 | 69 |

Based on the data shown in Table 4-49, high-end wholesale power production cost savings using smart CWs for peak load shifting are shown in Table 4-50 below. Note: as explained in Section 3.1.2.5, a CW's annual electricity consumption is split between CW machine-only consumption, and CW water-heater consumption. This split has a bearing on how peak-load-shift savings are evaluated. When CW consumption is shifted, it follows that both CW machine and CW water-heater consumption shift. However, only those CWs that are based on electricity-powered water heaters contribute to the savings resulting from peak-load shifting; the gas-fired water heaters do not contribute to the savings. We take this factor into account in estimating the CW savings shown in Table 4-50 below.

**Table 4-50**. Wholesale Cost Savings from Using Smart CWs for Peak Load Shifting – Optimistic View

| | Annual Hourly Energy Market Clearing Prices | | | Annual Energy Cost (No Load Shift) | | Annual Energy Cost Savings from 100% Peak Load Shift | |
|---|---|---|---|---|---|---|---|
| | Avg. On-Peak | Avg. Off-Peak | Avg. Shift-To Hours | On-Peak | Off-Peak | On-Peak Energy Moved to "Shift To" Hours | Savings |
| Market and Year | ($/MWh) | ($/MWh) | ($/MWh) | ($/yr) | ($/yr) | (kWh/yr) | ($/yr) |
| PJM 2006 | $50.64 | $39.44 | $39.44 | $2.52 | $3.81 | 49.69 | $0.56 |
| ERCOT 2008 | $105.56 | $67.09 | $67.09 | $5.25 | $6.48 | 49.69 | $1.91 |
| NYISO 2008 | $115.97 | $92.25 | $92.27 | $5.76 | $8.91 | 49.69 | $1.18 |
| NYISO 2006 | $85.05 | $67.44 | $67.41 | $4.23 | $6.52 | 49.69 | $0.88 |
| CAISO 2008 | $82.11 | $65.01 | $65.02 | $4.08 | $6.28 | 49.69 | $0.85 |

The high-end wholesale cost savings from using smart CWs for providing spinning reserves is shown in Table 4-51 below. Note: as was the case with peak-load shifting, we take into account the split in CW electricity consumption between CW machine usage and CW water heater usage. Furthermore, any CW spinning-reserves value comes only from CW machine consumption, because a temporary curtailment of CW operation does not mean that water heater operation is curtailed. The water heater is a separate appliance, and it will not turn off for say 10 minutes in response to a contingency signal to the CW. (Of course, a smart water heater might itself provide spinning reserves, but that is distinct from the spinning reserve value of a CW). This factor is taken into account in estimating CW spinning-reserve value as shown in Table 4-51 below.

**Table 4-51**. Wholesale Cost Savings from Using Smart CWs for Spinning Reserves – Optimistic View

| | Annual Hourly SR Market Clearing Prices | | | Annual Clothes Washer (Machine Only) SR Market Value | | |
|---|---|---|---|---|---|---|
| | Avg. On-Peak | Avg. Off-Peak | Avg. Shift-To Hours | On Peak: From Clothes Washer Load After 100% Shifted | Off-Peak: From Clothes Washer Off-Peak Load + 100% Load shifted from Peak to 'Shift To' Hours | Total Spinning Reserve Cost Savings |
| Market and Year | ($/MWh) | ($/MWh) | ($/MWh) | ($/yr) | ($/yr) | ($/yr) |
| PJM 2006 | $7.29 | $8.08 | $8.08 | $0.00 | $0.84 | $0.84 |
| ERCOT 2008 | $36.85 | $23.76 | $23.76 | $0.00 | $2.48 | $2.48 |
| NYISO 2008 | $14.84 | $8.56 | $8.56 | $0.00 | $0.89 | $0.89 |
| NYISO 2006 | $12.40 | $5.42 | $5.42 | $0.00 | $0.57 | $0.57 |
| CAISO 2008 | $13.26 | $3.56 | $3.57 | $0.00 | $0.37 | $0.37 |

The additional 6% optimistic electricity consumption and cost savings resulting from providing energy-use feedback to customers is shown below in Table 4-52.

**Table 4-52**. Additional 6% Savings Resulting from CW Consumption Feedback to Customers

| Market and Year | (kWh/yr) | ($/yr) |
|---|---|---|
| PJM 2006 | 9 | $0.38 |
| ERCOT 2008 | 9 | $0.70 |
| NYISO 2008 | 9 | $0.88 |
| NYISO 2006 | 9 | $0.64 |
| CAISO 2008 | 9 | $0.62 |

Finally, the overall high-end benefits (wholesale cost saving resulting from peak-load shifting, spinning reserves, consumer feedback, and their combined total) and cost (5% credit) are shown below in Table 4-53, expressed as benefits-to-cost percentages; and the percentages of total benefits individually attributable to peak-load shifting, spinning reserves, and feedback effect are shown below in Table 4-54.

**Table 4-53**. Smart CW Benefit (Peak Load Shift + Spinning Reserves + Feedback Effect)-to-Cost Ratio – Optimistic View

| | Grid Operational Cost Savings (Benefits) | Cost of Additional Energy Consumption at 5% Credit | Load Shift Benefits to Cost Ratio | Spinning Reserves Benefits to Cost Ratio | Feedback Effect Benefits to Cost Ratio | Total Benefits to Cost Ratio |
|---|---|---|---|---|---|---|
| Market and Year | ($/yr) | ($/yr) | (-) | (-) | (-) | (-) |
| PJM 2006 | $1.78 | $0.32 | 176% | 267% | 120% | **563%** |
| ERCOT 2008 | $5.10 | $0.59 | 326% | 425% | 120% | **871%** |
| NYISO 2008 | $2.95 | $0.73 | 161% | 122% | 120% | **403%** |
| NYISO 2006 | $2.09 | $0.54 | 163% | 105% | 120% | **389%** |
| CAISO 2008 | $1.84 | $0.52 | 164% | 72% | 120% | **356%** |

Table 4-54. Percentage of Total Smart CW Benefits Attributable to Load Shift, Spinning Reserves, and Feedback Effect - Optimistic View

| Market and Year | Peak-Load Shifting | Spinning Resreves | Feedback Effect |
|---|---|---|---|
| PJM 2006 | 31% | 47% | 21% |
| ERCOT 2008 | 37% | 49% | 14% |
| NYISO 2008 | 40% | 30% | 30% |
| NYISO 2006 | 42% | 27% | 31% |
| CAISO 2008 | 46% | 20% | 34% |

Thus, as can be observed from Table 4-53, the benefit–to-cost ratios overwhelmingly exceed 100% in all markets.

### 4.6.2 Low-End Pessimistic Results

We first present below in Table 4-55 the annual on-peak and off-peak electricity consumption, including the CW machine and CW water heater splits, based on the pessimistic assumptions presented in Section 3.1.

**Table 4-55**. CW On-Peak and Off-Peak Consumption Based on ELCAP Average Annual Day Load Shape and Pessimistic Assumptions

| ELCAP (1990) Clothes Washer Load Shape | | | | | 2010 Annual Clothes Washer On-Peak and Off-Peak Consumption | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Load Shape: | Average Day Daily Total | Annual On-Peak | Avg. No. of On-Peak Days/Year | Annual On-Peak To Total Ratio | Total Annual Consumption (Machine + Hot Water) | Total Annual Consumption (Machine Only) | Total Annual Consumption (Hot Water Only) | Annual On-Peak Consumption (Machine Only) | Annual Off-Peak Consumption (Machine Only) | Annual On-Peak Consumption (Hot Water Only) | Annual Off-Peak Consumption (Hot Water Only) |
| Start, Hour Ending: | 1 | 14 | | | | | | | | | |
| Through Hour Ending: | 24 | 17 | | | | | | | | | |
| | (kWh/day) | (kWh/day) | | | (kWh/yr) | (kWh/yr) | (kWh/yr) | (kWh/yr) | (kWh/yr) | (kWh/yr) | (kWh/yr) |
| | 0.29 | 0.06 | 261 | 0.15 | 209 | 105 | 105 | 16 | 88 | 16 | 88 |

Based on the data shown in Table 4-55, high-end wholesale power production cost savings using smart CWs for peak-load shifting are shown below in Table 4-56. As was the case with the high-end savings shown in Table 4-50, we take into account the effect that splitting consumption between CW machine and CW water heating has on the savings.

**Table 4-56**. Wholesale Cost Savings from Using Smart CWs for Peak Load Shifting – Pessimistic View

| | Annual Hourly Energy Market Clearing Prices | | | Annual Energy Cost (No Load Shift) | | Annual Energy Cost Savings from 18% Peak Load Shift | |
|---|---|---|---|---|---|---|---|
| | Avg. On-Peak | Avg. Off-Peak | Avg. Shift-To Hours | On-Peak | Off-Peak | On-Peak Energy Moved to "Shift To" Hours | Savings |
| Market and Year | ($/MWh) | ($/MWh) | ($/MWh) | ($/yr) | ($/yr) | (kWh/yr) | ($/yr) |
| PJM 2006 | $55.55 | $42.90 | $42.89 | $1.26 | $5.30 | 3.96 | $0.05 |
| ERCOT 2008 | $118.93 | $72.86 | $72.86 | $2.69 | $9.01 | 3.96 | $0.18 |
| NYISO 2008 | $120.41 | $94.80 | $94.81 | $2.73 | $11.72 | 3.96 | $0.10 |
| NYISO 2006 | $93.91 | $72.50 | $72.50 | $2.13 | $8.97 | 3.96 | $0.08 |
| CAISO 2008 | $88.03 | $68.56 | $68.56 | $1.99 | $8.48 | 3.96 | $0.08 |

The low-end wholesale cost savings from using smart CWs for providing spinning reserves is shown in Table 4-57 below. As was the case with the high-end savings shown in Table 4-51, we take into account the effect that splitting consumption between CW machine and CW water heating has on the savings.

**Table 4-57**. Wholesale Cost Savings from Using Smart CWs for Spinning Reserves - Pessimistic View

| | Annual Hourly SR Market Clearing Prices | | | Annual Clothes Washer (Machine Only) SR Market Value | | |
|---|---|---|---|---|---|---|
| | Avg. On-Peak | Avg. Off-Peak | Avg. Shift-To Hours | On Peak: From Clothes Washer Load After 18% Shifted | Off-Peak: From Clothes Washer Off-Peak Load + 18% Load shifted from Peak to 'Shift To' Hours | Total Spinning Reserve Cost Savings |
| Market and Year | ($/MWh) | ($/MWh) | ($/MWh) | ($/yr) | ($/yr) | ($/yr) |
| PJM 2006 | $7.30 | $8.29 | $8.29 | $0.02 | $0.17 | $0.19 |
| ERCOT 2008 | $37.42 | $25.57 | $25.58 | $0.11 | $0.52 | $0.64 |
| NYISO 2008 | $14.38 | $9.16 | $9.16 | $0.04 | $0.19 | $0.23 |
| NYISO 2006 | $16.02 | $7.62 | $7.62 | $0.05 | $0.16 | $0.20 |
| CAISO 2008 | $14.90 | $4.29 | $4.29 | $0.04 | $0.09 | $0.13 |

The additional 3% pessimistic electricity consumption and cost savings resulting from providing energy-use feedback to customers is shown below in Table 4-58.

**Table 4-58**. Additional 3% Savings Resulting from CW Consumption Feedback to Customers

| Market and Year | (kWh/yr) | ($/yr) |
|---|---|---|
| PJM 2006 | 4 | $0.19 |
| ERCOT 2008 | 4 | $0.34 |
| NYISO 2008 | 4 | $0.43 |
| NYISO 2006 | 4 | $0.32 |
| CAISO 2008 | 4 | $0.31 |

Finally, the low-end benefits (wholesale cost saving resulting from peak-load shifting, spinning reserves, consumer feedback, and their combined total) and cost (5% credit) are shown below in Table

4-59, expressed as benefits-to-cost percentages; and the percentages of total benefits individually attributable to peak-load shifting, spinning reserves, and feedback effect are shown below in Table 4-60.

**Table 4-59**. Smart CW Benefit (Peak Load Shift + Spinning Reserves + Feedback Effect)-to-Cost Ratio – Pessimistic View

| Market and Year | Grid Operational Cost Savings (Benefits) ($/yr) | Cost of Additional Energy Consumption at 5% Credit ($/yr) | Load Shift Benefits to Cost Ratio (-) | Spinning Reserves Benefits to Cost Ratio (-) | Feedback Effect Benefits to Cost Ratio (-) | Total Benefits to Cost Ratio (-) |
|---|---|---|---|---|---|---|
| PJM 2006 | $0.44 | $0.33 | 15% | 59% | 60% | **134%** |
| ERCOT 2008 | $1.17 | $0.59 | 31% | 109% | 60% | **200%** |
| NYISO 2008 | $0.77 | $0.72 | 14% | 32% | 60% | **106%** |
| NYISO 2006 | $0.62 | $0.55 | 15% | 37% | 60% | **112%** |
| CAISO 2008 | $0.52 | $0.52 | 15% | 25% | 60% | **100%** |

Table 4-60. Percentage of Total Smart CW Benefits Attributable to Load Shift, Spinning Reserves, and Feedback Effect - Pessimistic View

| Market and Year | Peak-Load Shifting | Spinning Resreves | Feedback Effect |
|---|---|---|---|
| PJM 2006 | 11% | 44% | 45% |
| ERCOT 2008 | 16% | 54% | 30% |
| NYISO 2008 | 13% | 30% | 57% |
| NYISO 2006 | 14% | 33% | 54% |
| CAISO 2008 | 15% | 25% | 60% |

Thus, as can be observed from Table 4-59, the benefits to cost ratios exceed 100% even for the pessimistic set of assumptions in all markets.

## 4.7 Benefit-to-Cost Ratios: Smart Dishwashers (DWs)

In this section, we estimate the benefit-to-cost ratio of smart DWs in various markets based on both optimistic and pessimistic sets of assumptions.

### 4.7.1 High-End Optimistic Results

We first present below in Table 4-61 the DW annual on-peak and off-peak electricity consumption, including the DW machine and DW water heater splits, based on the optimistic assumptions presented in Section 3.1.

**Table 4-61**. DW On-Peak and Off-Peak Consumption Based on ELCAP Average Annual Day Load Shape and Optimistic Assumptions

| ELCAP (1990) DishWasher Load Shape | | | | | 2010 Annual DishWasher On-Peak and Off-Peak Consumption | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Load Shape: | Average Day | Annual | | | Total Annual Consumption (Machine + Hot Water) | Total Annual Consumption (Machine Only) | Total Annual Consumption (Hot Water Only) | Annual On-Peak Consumption (Machine Only) | Annual Off-Peak Consumption (Machine Only) | Annual On-Peak Consumption (Hot Water Only) | Annual Off-Peak Consumption (Hot Water Only) |
| | Daily Total | On-Peak | Avg. No. of On-Peak Days/Year | Annual On-Peak To Total Ratio | | | | | | | |
| Start, Hour Ending: | 1 | 13 | | | | | | | | | |
| Through Hour Ending: | 24 | 18 | | | | | | | | | |
| | (kWh/day) | (kWh/day) | | | (kWh/yr) | (kWh/yr) | (kWh/yr) | (kWh/yr) | (kWh/yr) | (kWh/yr) | (kWh/yr) |
| | 0.33 | 0.08 | 365 | 0.25 | 312 | 156 | 156 | 40 | 116 | 40 | 116 |

Based on the data shown in Table 4-61, high-end wholesale power-production cost savings using smart CWs for peak load shifting are shown in Table 4-62 below. As was the case with the high-end savings for CWs shown in Table 4-50, we take into account the effect that splitting consumption between DW machine and DW water heating has on the savings.

**Table 4-62**. Wholesale Cost Savings from Using Smart DWs for Peak Load Shifting – Optimistic View

| | Annual Hourly Energy Market Clearing Prices | | | Annual Energy Cost (No Load Shift) | | Annual Energy Cost Savings from 100% Peak Load Shift | |
|---|---|---|---|---|---|---|---|
| | Avg. On-Peak | Avg. Off-Peak | Avg. Shift-To Hours | On-Peak | Off-Peak | On-Peak Energy Moved to "Shift To" Hours | Savings |
| Market and Year | ($/MWh) | ($/MWh) | ($/MWh) | ($/yr) | ($/yr) | (kWh/yr) | ($/yr) |
| PJM 2006 | $50.64 | $39.44 | $39.44 | $2.82 | $6.42 | 55.62 | $0.62 |
| ERCOT 2008 | $105.56 | $67.09 | $67.09 | $5.87 | $10.92 | 55.62 | $2.14 |
| NYISO 2008 | $115.97 | $92.25 | $92.27 | $6.45 | $15.02 | 55.62 | $1.32 |
| NYISO 2006 | $85.05 | $67.44 | $67.41 | $4.73 | $10.98 | 55.62 | $0.98 |
| CAISO 2008 | $82.11 | $65.01 | $65.02 | $4.57 | $10.58 | 55.62 | $0.95 |

The high-end wholesale cost savings from using smart DWs for providing spinning reserves is shown in Table 4-63 below. Once again, we take into account the effect that splitting consumption between DW machine and DW water heating has on the savings.

**Table 4-63**. Wholesale Cost Savings from Using Smart CWs for Spinning Reserves – Optimistic View

| | Annual Hourly SR Market Clearing Prices | | | Annual DishWasher (Machine Only) SR Market Value | | |
|---|---|---|---|---|---|---|
| | Avg. On-Peak | Avg. Off-Peak | Avg. Shift-To Hours | On Peak: From DishWasher Load After 100% Shifted | Off-Peak: From DishWasher Off Peak Load + 100% Load shifted from Peak to 'Shift To' Hours | Total Spinning Reserve Cost Savings |
| Market and Year | ($/MWh) | ($/MWh) | ($/MWh) | ($/yr) | ($/yr) | ($/yr) |
| PJM 2006 | $7.29 | $8.08 | $8.08 | $0.00 | $1.26 | $1.26 |
| ERCOT 2008 | $36.85 | $23.76 | $23.76 | $0.00 | $3.71 | $3.71 |
| NYISO 2008 | $14.84 | $8.56 | $8.56 | $0.00 | $1.34 | $1.34 |
| NYISO 2006 | $12.40 | $5.42 | $5.42 | $0.00 | $0.85 | $0.85 |
| CAISO 2008 | $13.26 | $3.56 | $3.57 | $0.00 | $0.56 | $0.56 |

The additional 6% optimistic electricity consumption and cost savings resulting from providing energy-use feedback to customers is shown below in Table 4-64.

**Table 4-64**. Additional 6% Savings Resulting from DW Consumption Feedback to Customers

| Market and Year | (kWh/yr) | ($/yr) |
|---|---|---|
| PJM 2006 | 13 | $0.55 |
| ERCOT 2008 | 13 | $1.01 |
| NYISO 2008 | 13 | $1.29 |
| NYISO 2006 | 13 | $0.94 |
| CAISO 2008 | 13 | $0.91 |

Finally, the high-end benefit (wholesale cost saving resulting from peak-load shifting, spinning reserves, consumer feedback, and their combined total) and cost (5% credit) are shown below in , Table 4-65, expressed as benefits-to-cost percentages; and the percentages of total benefits individually attributable to peak-load shifting, spinning reserves, and feedback effect are shown below in Table 4-66.

**Table 4-65**. Smart CW Benefit (Peak Load Shift + Spinning Reserves + Feedback Effect)-to-Cost Ratio – Optimistic View

| | Grid Operational Cost Savings (Benefits) | Cost of Additional Energy Consumption at 5% Credit | Load Shift Benefits to Cost Ratio | Spinning Reserves Benefits to Cost Ratio | Feedback Effect Benefits to Cost Ratio | Total Benefits to Cost Ratio |
|---|---|---|---|---|---|---|
| Market and Year | ($/yr) | ($/yr) | (-) | (-) | (-) | (-) |
| PJM 2006 | $2.44 | $0.46 | 135% | 273% | 120% | **528%** |
| ERCOT 2008 | $6.85 | $0.84 | 255% | 443% | 120% | **817%** |
| NYISO 2008 | $3.94 | $1.07 | 123% | 124% | 120% | **367%** |
| NYISO 2006 | $2.77 | $0.79 | 125% | 108% | 120% | **353%** |
| CAISO 2008 | $2.41 | $0.76 | 125% | 73% | 120% | **319%** |

Table 4-66. Percentage of Total Smart DW Benefits Attributable to Load Shift, Spinning Reserves, and Feedback Effect - Optimistic View

| Market and Year | Peak-Load Shifting | Spinning Resreves | Feedback Effect |
|---|---|---|---|
| PJM 2006 | 26% | 52% | 23% |
| ERCOT 2008 | 31% | 54% | 15% |
| NYISO 2008 | 33% | 34% | 33% |
| NYISO 2006 | 35% | 31% | 34% |
| CAISO 2008 | 39% | 23% | 38% |

Thus, as can be observed from Table 4-65, the benefit–to-cost ratios overwhelmingly exceed 100% in all markets.

### 4.7.2 Low-End Pessimistic Results

We first present below in Table 4-67 the annual on-peak and off-peak electricity consumption, including the DW machine and DW hot water splits, based on the pessimistic assumptions presented in Section 3.1.

Table 4-67. DW On-Peak and Off-Peak Consumption Based on ELCAP Average Annual Day Load Shape and Pessimistic Assumptions

| ELCAP (1990) DishWasher Load Shape | | | | | 2010 Annual DishWasher On-Peak and Off-Peak Consumption | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Load Shape: | Average Day Daily Total | Annual On-Peak | Avg. No. of On-Peak Days/Year | Annual On-Peak To Total Ratio | Total Annual Consumption (Machine + Hot Water) | Total Annual Consumption (Machine Only) | Total Annual Consumption (Hot Water Only) | Annual On-Peak Consumption (Machine Only) | Annual Off-Peak Consumption (Machine Only) | Annual On-Peak Consumption (Hot Water Only) | Annual Off-Peak Consumption (Hot Water Only) |
| Start, Hour Ending: | 1 | 14 | | | | | | | | | |
| Through Hour Ending: | 24 | 17 | | | | | | | | | |
| | (kWh/day) | (kWh/day) | | | (kWh/yr) | (kWh/yr) | (kWh/yr) | (kWh/yr) | (kWh/yr) | (kWh/yr) | (kWh/yr) |
| | 0.33 | 0.05 | 261 | 0.12 | 312 | 156 | 156 | 18 | 138 | 18 | 138 |

Based on the data shown in Table 4-67, high-end wholesale power production cost savings using smart DWs for peak load shifting are shown below in Table 4-68. Once again note that we take into account the effect that splitting consumption split between DW machine and DW water heating has on the savings.

**Table 4-68**. Wholesale Cost Savings from Using Smart CWs for Peak Load Shifting – Pessimistic View

| | Annual Hourly Energy Market Clearing Prices | | | Annual Energy Cost (No Load Shift) | | Annual Energy Cost Savings from 25% Peak Load Shift | |
|---|---|---|---|---|---|---|---|
| | Avg. On-Peak | Avg. Off-Peak | Avg. Shift-To Hours | On-Peak | Off-Peak | On-Peak Energy Moved to "Shift To" Hours | Savings |
| Market and Year | ($/MWh) | ($/MWh) | ($/MWh) | ($/yr) | ($/yr) | (kWh/yr) | ($/yr) |
| PJM 2006 | $55.55 | $42.90 | $42.89 | $1.41 | $8.28 | 6.24 | $0.08 |
| ERCOT 2008 | $118.93 | $72.86 | $72.86 | $3.03 | $14.06 | 6.24 | $0.29 |
| NYISO 2008 | $120.41 | $94.80 | $94.81 | $3.07 | $18.29 | 6.24 | $0.16 |
| NYISO 2006 | $93.91 | $72.50 | $72.50 | $2.39 | $13.99 | 6.24 | $0.13 |
| CAISO 2008 | $88.03 | $68.56 | $68.56 | $2.24 | $13.23 | 6.24 | $0.12 |

The low-end wholesale cost savings from using smart DWs for providing spinning reserves is shown in Table 4-69 below. Once again note that we take into account the effect that splitting consumption between DW machine and DW water heating has on the savings.

**Table 4-69**. Wholesale Cost Savings from Using Smart CWs for Spinning Reserves – Pessimistic View

| | Annual Hourly SR Market Clearing Prices | | | Annual DishWasher (Machine Only) SR Market Value | | |
|---|---|---|---|---|---|---|
| | Avg. On-Peak | Avg. Off-Peak | Avg. Shift-To Hours | On Peak: From DishWasher Load After 25% Shifted | Off-Peak: From DishWasher Off-Peak Load + 25% Load shifted from Peak to 'Shift To' Hours | Total Spinning Reserve Cost Savings |
| Market and Year | ($/MWh) | ($/MWh) | ($/MWh) | ($/yr) | ($/yr) | ($/yr) |
| PJM 2006 | $7.30 | $8.29 | $8.29 | $0.02 | $0.27 | $0.29 |
| ERCOT 2008 | $37.42 | $25.57 | $25.58 | $0.12 | $0.82 | $0.93 |
| NYISO 2008 | $14.38 | $9.16 | $9.16 | $0.04 | $0.29 | $0.34 |
| NYISO 2006 | $16.02 | $7.62 | $7.62 | $0.05 | $0.24 | $0.29 |
| CAISO 2008 | $14.90 | $4.29 | $4.29 | $0.05 | $0.14 | $0.18 |

The additional 3% pessimistic electricity consumption and cost savings resulting from providing energy-use feedback to customers is shown below in Table 4-70.

**Table 4-70**. Additional 3% Savings Resulting from DW Consumption Feedback to Customers

| Market and Year | (kWh/yr) | ($/yr) |
|---|---|---|
| PJM 2006 | 7 | $0.29 |
| ERCOT 2008 | 7 | $0.51 |
| NYISO 2008 | 7 | $0.64 |
| NYISO 2006 | 7 | $0.49 |
| CAISO 2008 | 7 | $0.46 |

Finally, low-end benefits (wholesale cost saving resulting from peak-load shifting, spinning reserves, consumer feedback, and their combined total) and cost (5% credit) are shown below in Table 4-71, expressed as benefits-to-cost percentages; and the percentages of total benefits individually attributable to peak-load shifting, spinning reserves, and feedback effect are shown below in Table 4-72.

**Table 4-71**. Smart DW Benefit (Peak Load Shift + Spinning Reserves + Feedback Effect)-to-Cost Ratio – Pessimistic View

| | Grid Operational Cost Savings (Benefits) | Cost of Additional Energy Consumption at 5% Credit | Load Shift Benefits to Cost Ratio | Spinning Reserves Benefits to Cost Ratio | Feedback Effect Benefits to Cost Ratio | Total Benefits to Cost Ratio |
|---|---|---|---|---|---|---|
| Market and Year | ($/yr) | ($/yr) | (-) | (-) | (-) | (-) |
| PJM 2006 | $0.66 | $0.48 | 16% | 59% | 60% | **136%** |
| ERCOT 2008 | $1.73 | $0.85 | 34% | 109% | 60% | **203%** |
| NYISO 2008 | $1.14 | $1.07 | 15% | 32% | 60% | **107%** |
| NYISO 2006 | $0.92 | $0.82 | 16% | 36% | 60% | **112%** |
| CAISO 2008 | $0.77 | $0.77 | 16% | 24% | 60% | **99%** |

Table 4-72. Percentage of Total Smart DW Benefits Attributable to Load Shift, Spinning Reserves, and Feedback Effect - Pessimistic View

| Market and Year | Peak-Load Shifting | Spinning Resreves | Feedback Effect |
|---|---|---|---|
| PJM 2006 | 12% | 44% | 44% |
| ERCOT 2008 | 17% | 54% | 30% |
| NYISO 2008 | 14% | 30% | 56% |
| NYISO 2006 | 15% | 32% | 54% |
| CAISO 2008 | 16% | 24% | 60% |

Thus, as can be observed from Table 4-71, the benefits to cost ratios exceed 100% even for the pessimistic set of assumptions in all markets except CAISO 2008 where it is about 100%.

# 5.0 Conclusions and Future Work

In this report, we presented the results of an analytical cost/benefit study of residential "smart appliances"[1] from a utility/grid perspective. This study was prepared as an independent technical analysis of a joint stakeholder[2] petition to the ENERGY STAR program within the EPA and DOE.

Benefits were defined as the savings in wholesale power-production costs resulting from smart appliances shifting their operation from peak to off-peak hours, and smart appliances providing spinning reserves through temporary curtailment of their operation. Cost was defined as the percent energy credit the petition was seeking, and in absolute monetary terms, this cost is estimated by applying the five percent credit to each appliance's annual grid operating expenses.

We first presented our cost/benefit analytical model in general, and then we applied this model to individual appliances to evaluate their benefit-to-cost ratios. In estimating benefits and costs, we made some input assumptions, and presented a rationale for the values chosen. We also presented the annual load shape of each appliance, as a basis for the cost/benefit model. Finally, benefits and costs were estimated based on historical wholesale market clearing prices from several major markets in the U.S. From the benefit-to-cost ratio for each appliance, we observed that for all appliances, the benefit-to-cost ratios either exceeded or were close to 100% for both the optimistic assumptions and pessimistic set assumptions used in our analysis.

Given that a significant fraction of total benefits are due to the use of smart appliances as sources of spinning reserves, further work is needed to actually use appliances in spinning reserve applications, to better quantify the amount of spinning reserve capacity that can be obtained from appliances at different hours of the day and night and in different seasons, and to correlate this appliance spinning reserve capacity to power system spinning reserve needs at different times.

Finally, it must be emphasized that in this work we have shown that the use of smart appliances leads to power grid benefits manifested as savings in wholesale power production costs. These savings could then be passed on to rate-paying customers via the utility rate-making process. The next step would be to continue this cost/benefit analysis to quantify how these wholesale grid operating-cost savings translate into net customer benefits at the retail level.

[1] "Smart Appliances" are capable of either shifting their time of operation or curtailing their operation temporarily upon request. A more detailed definition is presented in Section 1.1.

[2] Stakeholders include Association of Home Appliance Manufacturers (AHAM), American Council for an Energy-Efficient Economy, Natural Resources Defense Council, Consumer Federation of America, and many others.

# 6.0 References


American Council for an Energy Efficient Economy (ACEEE). 2010. *Advanced Metering Initiatives andResidential Feedback Programs: A Meta-Review for Household Electricity-Saving Opportunities*. Available at http://www.aceee.org/research-report/e105.

Association of Home Appliance Manufacturers (AHAM). 2009. Shipment Weighted Average Data. Personal communication with AHAM.

Association of Home Appliance Manufacturers (AHAM). 2010. *Assessment of Communication Standards for Smart Appliances: The Home Appliance Industry's Technical Evaluation of Communication Protocols*. Washington, D.C. Accessed December 9, 2010 at http://www.aham.org/ht/a/GetDocumentAction/i/50696.

California Independent System Operator (CAISO). 2008. *OASIS.* Accessed December 9, 2010 at http://oasishis.caiso.com/.

U.S. Department of Energy (DOE). 2010. *Appliances & Commercial Equipment Standards*. Accessed November 29, 2010 at http://www1.eere.energy.gov/buildings/appliance_standards/residential_products.html (last updated May 11, 2010).

U.S. Department of Energy (DOE). 2010a. Press Release, U.S. Department of Energy, Secretary Chu Announces Two Million Smart Grid Meters Installed Nationwide (August 31, 2010). Washington, D.C. Accessed September 30, 2010 at http://www.energy.gov/news/9433.htm.

U.S. Department of Energy (DOE). 2010b. 20% Wind Energy by 2030: Increasing Wind Energy's Contribution to U.S. Electricity Supply. Accessed September 30, 2010 at http://www1.eere.energy.gov/windandhydro/wind_2030.html.

US Department of Energy, Office of Energy Efficiency and Renewable Energy (EERE). 2009. "2006 Residential Energy End-Use Splits by Fuel Type – Table 2.1.5. Buildings Energy Data Book. Accessed October 14, 2010 at http://buildingsdatabook.eren.doe.gov/TableView.aspx?table=2.1.5 (last updated October, 2009).

Energy Information Administration (EIA). 2010. U.S. Energy Information Administration, Annual Energy Outlook 2010. Projection and analysis of US energy supply, demand, and prices through 2035. Accessed January 5, 2011 at http://www.eia.doe.gov/oiaf/archive/aeo10/index.html (last updated May 11, 2010).

Electric Reliability Council of Texas (ERCOT). 2008. Ancillary Services Offer Selected - Daily Reports Archive. Accessed December 9, 2010 at http://www.ercot.com/mktinfo/prices/asoffer/2008/index.

Eto JH, J Nelson-Hoffman, C Torres, S Hirth, B Yinger, J Kueck, B Kirby, C Bernier, R Wright, A Barat, and DS Watson. 2007. Demand Response Spinning Reserve Demonstration. LBNL-62761. Ernest Orlando Lawrence Berkeley National Laboratory, Berkeley, California.

Faruqui A, S Sergici, and A Sharif. 2009. "The Impact of Informational Feedback on Energy Consumption – A Survey of the Experimental Evidence." *Energy* (in press).

Federal Energy Regulatory Commission (FERC). 2009. *A National Assessment of Demand Response Potential*. FERC June 2009 Staff Report. Accessed November 26, 2010 at http:// www.ferc.gov/legal/staff-reports/06-09-demand-response.pdf.

Fischer C. 2008. "Feedback on Household Electricity Consumption: A Tool for Saving Energy?" *Energy Efficiency* 1(1):79-104. DOI: 10.1007/s12053-008-9009-7. Accessed December 9, 2010 at www.springerlink.com/index/276m42024x61wh1h.pdf.

Kirby BJ and JD Kueck. 2003. *Spinning Reserve from Pump Load: A Technical Findings Report to the California Department of Water Resources*. ORNL/TM-2003/99, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Kirby BJ. 2003. *Spinning Reserve from Responsive Loads*. ORNL/TM-2003/19, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Kueck JD, BJ Kirby, MR Ally, and CK Rice. 2008. *Prediction of Air Conditioning Load Response for Providing Spinning Reserve*. ORNL/TM-2008/227, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

North American Electricity Reliability Corporation (NERC). 2002. *Control Performance Standards*. Accessed September 30, 2010 at http://www.nerc.com/docs/oc/ps/tutorcps.pdf.

North American Electricity Reliability Corporation (NERC). 2005. *Disturbance Control Performance 2005*. BAL-002-0. Accessed October 04, 2010 at http:// www.nerc.com/files/BAL-002-0.pdf.

New York Independent System Operator (NYISO). 2006 and 2008. *Markets and Operations –Custom Reports – Real-Time Market – Ancillary Services*. Accessed December 9, 2010 at http://www.nyiso.com/public/markets_operations/market_data/custom_report/index.jsp?report=rt_ancillary.

PJM. 2006. *Mid-Atlantic Synchronized Reserve Zone Preliminary Billing Data*. Accessed December 9, 2010 at http://www.pjm.com/markets-and-operations/market-settlements/preliminary-billing-reports/east-spinning-reserve.aspx.

Pratt RG, CC Conner, EE Richman, KG Ritland, WF Sandusky, and ME Taylor. 1989. *Description of Electric Energy Use in Single-Family Residences in the Pacific Northwest*. (End-Use Load and Consumer Assessment Program [ELCAP]). DOE/BP-13795-21, prepared for Bonneville Power Administration by Pacific Northwest Laboratory, Richland, Washington.

Western Electricity Coordinating Council (WECC). 2006. NERC/WECC Minimum Operating Reliability Standards, Standart BAL-STD-002-1 — *Disturbance Control Performance. 2006*. Accessed October 14, 2010 at http://www.wecc.biz/Documents/2006/Standards/BAL-STD-002-1_ORSTF_Version_Approved_by_MIC_October_2006.pdf.

Wellinghoff J, DL Morenoff and ME Tighe. 2008. *Creating Regulatory Structures for Robust Demand Response Participation in Organized Wholesale Electric Markets.* Federal Energy Regulatory Commission (FERC). Accessed November 26, 2010 at http://www.ferc.gov/about/com-mem/wellinghoff/ACEEE_article.pdf.

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