CHAPTER 5. ENGINEERING ANALYSIS

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CHAPTER 5. ENGINEERING ANALYSIS

5.1 INTRODUCTION

After conducting the screening analysis, the U.S. Department of Energy (DOE) performed an engineering analysis based on the remaining design options. The engineering analysis consists of estimating the energy and water consumption and costs of residential clothes washers at various levels of increased efficiency. This section provides an overview of the engineering analysis (section 5.1), considers technologies that are unable to be analyzed for this rulemaking (section 5.2), discusses product classes (section 5.3), establishes baseline and incremental efficiency levels (section 5.4), explains the methodology used during data gathering (section 5.5) and discusses the analysis and results (section 5.6).

The primary inputs to the engineering analysis are baseline information from the market and technology assessment (chapter 3 of this technical support document (TSD)) and technology options from the screening analysis (chapter 4). Additional inputs include cost and energy efficiency data, which DOE received from the Association of Home Appliance Manufacturers (AHAM) and qualified and supplemented through teardown analysis and manufacturer interviews. The primary output of the engineering analysis is a set of cost-efficiency curves. In the subsequent markups analysis (chapter 6), DOE determines customer (*i.e.* product purchaser) prices by applying distribution markups, sales tax and contractor markups. After applying these markups, the cost-efficiency curves serve as the input to the building energy-use and end-use load characterization (chapter 7), and the life-cycle cost (LCC) and payback period (PBP) analyses (chapter 8).

DOE typically structures its engineering analysis around one of three methodologies. These are: (1) the design-option approach, which provides the incremental costs of adding to a baseline model design options that will improve its efficiency; (2) the efficiency-level approach, which provides the relative costs of achieving increases in energy efficiency levels, without regard to the particular design options used to achieve such increases; and (3) the cost-assessment (or reverse-engineering) approach, which provides "bottom-up" manufacturing cost assessments for achieving various levels of increased efficiency, based on detailed data regarding costs for parts and material, labor, shipping/packaging, and investment for models that operate at particular efficiency levels

DOE conducted the engineering analyses for the top-loading standard and front-loading standard product classes using a combination of the cost-assessment approach and the efficiency-level approach. The cost-assessment approach provides an accurate means for estimating a single manufacturer's incremental manufacturing costs for achieving various levels of increased efficiency. This approach involves physically disassembling commercially available products to develop cost-efficiency relationships for each manufacturer's product lines. Because each manufacturer may choose a different path to achieve higher levels of efficiency, an efficiency-level approach produces an industry-wide cost-efficiency relationship for each product class. DOE developed cost-efficiency relationships for the top-loading standard and front-loading standard product classes by calculating the market-weighted average of the individual cost-efficiency relationships it developed for each manufacturer.

Because less data was available for the top-loading compact and front-loading compact product classes, DOE used the design-option approach to develop the cost-efficiency relationships for these product classes. For the top-loading compact product class, DOE developed the cost-efficiency relationship by estimating the incremental costs of adding specific design options to a baseline model that would provide sufficient improvement in efficiency to achieve the higher efficiency levels considered for the analysis. For the front-loading compact product class, DOE estimated the efficiency of a baseline product by extrapolating the rated efficiencies of front-loading clothes washers with capacities nearing those that delineate the compact product class (i.e., 1.6 to 3.0 cubic feet). DOE then estimated the incremental cost of adding specific design options to this baseline model that would improve its efficiency enough to achieve the higher efficiency level considered for the analysis.

5.2 TECHNOLOGIES UNABLE TO BE INCLUDED IN THE PRELIMINARY ANALYSIS

In performing the engineering analysis, DOE did not consider certain technologies could not be evaluated for one or more of the following reasons: (1) data are not available to evaluate the energy efficiency characteristics of the technology; (2) available data suggested that the efficiency benefits of the technology would be negligible; and (3) certain technologies cannot be measured according to the conditions and methods specified in the DOE clothes washer test procedure (10 CFR 430, subpart B, appendix J2).

5.2.1 Adaptive Controls

In the notice of proposed rulemaking issued on September 21, 2010 (75 FR 57556) (hereinafter referred to as the September 2010 TP NOPR), DOE stated that it was aware of multiple clothes washer models available on the market that use adaptive control technologies to respond to measured or inferred load size and fabric mix. However, these models have since been discontinued, and DOE is unaware of any other clothes washers currently available on the market offering adaptive controls other than adaptive fill control. Adaptive controls could allow a clothes washer to sense the fabric mix and soil level of a wash load, for example, and then adjust wash parameters such as the number of rinses, cycle time, and water temperatures accordingly. Because of the lack of commercially available clothes washers with adaptive features, however, DOE did not amend the test procedure at appendix J2 to include provisions for measuring the energy consumption of clothes washers offering adaptive controls other than adaptive fill control. For this reasons, DOE did not include adaptive controls in its engineering analysis.

5.2.2 Improved Horizontal-Axis Washer Drum Design

Although several manufacturers have claimed improved wash performance and greater utility from improved drum designs for front-loading clothes washers, DOE is unaware of any publicly available data to corroborate a decrease in cycle time or energy or water consumption as a result of implementing this design option in residential clothes washers. Therefore, DOE did not analyze this design option for the final analysis.

5.2.3 Reduced Thermal Mass

Reduced thermal mass describes minimizing the amount of energy consumed by heating the wash tub to the temperature of the wash water. DOE research suggests that manufacturers typically already use tubs with low thermal mass for all clothes washers and that there is no practicable way to manufacture clothes washers with significantly lower thermal mass beyond the current practice. DOE is unaware of any data available regarding efficiency improvements related to further decreasing the thermal mass of wash tubs, and therefore did not consider this technology in its final analysis.

5.2.4 Silver Ion Injection

Silver ion injection provides an alternative to the traditional method of sanitizing clothes using a hot water wash. Silver ion injection works by electrolyzing pure silver during the wash and rinse cycles, and releasing the ions into the wash basket to sanitize the basket and wash load. While this technology option appears to offer an efficiency improvement by eliminating the need for high wash water temperatures, the current DOE test procedure does not capture this efficiency gain. Additionally, DOE lacks data on the reduction in warm and hot water cycles associated with silver ion injection and is not aware of any test procedures that could be used to measure any energy savings resulting from the use of silver ion injection. Because of this, DOE was unable to consider silver ion injection for further analysis

5.2.5 Tighter Tub Tolerance

The tighter tub tolerance technology option reduces the annular volume between the inner wash basket and the outer tub and hence reduces the total amount of water required for a fill cycle. As a result of discussions with manufacturers, DOE believes this technology option has reached its limit for efficiency gains. Decreasing the space between the wash basket and the tub any further could create problems such as “suds lock,” whereby suds remain between the wash basket and tub; improper draining during the spin cycle; noise; and vibration, thereby negatively impacting product utility. Therefore, DOE did not consider this design option in its engineering analysis.

Table 5.2.1 shows the final list of design options that DOE retained for the engineering analysis.

Table 5.2.1 Retained Design Options for Residential Clothes Washer Engineering Analysis

1. Advanced agitation concepts for top-loading machines
2. Automatic water fill control
3. Direct-drive motor
4. Horizontal-axis design
5. Horizontal-axis design with recirculation
6. Hot water circulation loop
7. Improved fill control
8. Improved water extraction to lower remaining moisture content
9. Increased motor efficiency
10. Low-standby-power electronic controls
11. Spray rinse or similar water-reducing rinse technology
12. Thermostatically controlled mixing valves

5.3 PRODUCT CLASSES ANALYZED

DOE separated residential clothes washers into product classes. In general, the criteria for separation into different classes are (1) type of energy used (natural gas or electricity), and (2) capacity or other performance-related features such as those that provide utility to the consumer, or others deemed appropriate by the Secretary that would justify the establishment of a separate energy conservation standard. (42 U.S.C. 6295 (q)) As discussed in chapter 3 of this TSD, DOE has separated residential clothes washers into the following four product classes:

- Top-loading, compact (less than 1.6 cubic feet capacity);
- Top-loading, standard (1.6 cubic feet or greater capacity);
- Front-loading, compact (less than 1.6 cubic feet capacity); and
- Front-loading, standard (1.6 cubic feet or greater capacity).

5.4 EFFICIENCY LEVELS

For residential clothes washers, energy conservation standard levels are currently defined by two factors—modified energy factor (MEF) and water consumption factor (WF). MEF is calculated as the clothes container capacity in cubic feet divided by the sum, expressed in kilowatt-hours (kWh), of: (1) the total weighted per-cycle hot water energy consumption; (2) the total weighted per-cycle machine electrical energy consumption; and (3) the per-cycle energy consumption for removing moisture from a test load. WF is calculated as the weighted per-cycle water consumption of the cold wash/cold rinse cycle divided by the clothes container capacity in cubic feet.

For residential clothes washers, MEF and WF are calculated as follows:

$MEF = C / (HE_T + ME_T + D_E)$

where:

C= Clothes container capacity (ft^3)
HE_T = Total weighted per-cycle hot water energy consumption (kWh)
ME_T = Total weighted per-cycle machine electrical energy consumption (kWh)
D_E= Per-cycle energy consumption for removal of moisture from test load (kWh)

$WF = Q_T / C$

where:

Q_T= Total weighted per-cycle water consumption (gallons)
C = Clothes container capacity (ft^3).

Section 310 of the Energy Independence and Security Act of 2007 (EISA 2007), Pub. L. 110-140, amended section 325 of the Energy Policy and Conservation Act (EPCA) of 1975, Pub. L. 94-163, (42 U.S.C. 6291-6309) to require that the test procedure for clothes washers be amended to include measurement of standby mode and off mode energy use, taking into consideration the most current versions of Standards 62301 and 62087 of the International Electrotechnical Commission (IEC)[a]. EPCA, as amended by EISA 2007, also required that any final rule establishing or revising a standard for a covered product, adopted after July 1, 2010, shall incorporate standby mode and off mode energy use into a single amended or new standard, if feasible. If not feasible, the Secretary shall prescribe within the final rule a separate standard for standby mode and off mode energy consumption. (42 U.S.C. 6295(gg))

DOE initiated a rulemaking in September 2010 to revise the test procedure for clothes washers to provide for measurement of standby mode and off mode energy use, as well as to address issues with the active mode provisions of the test procedure. In the subsequent final rule, DOE integrated standby and off mode energy use into the revised test procedure by establishing an "integrated modified energy factor" (IMEF), which also includes amended calculations of energy use in the active mode. The revised test procedure, designated as appendix J2, also establishes an "integrated water factor" (IWF), a metric that incorporates water usage from all cycles included in the energy test cycle rather than just the cold wash cycle. (10 CFR 430, subpart B, appendix J2)

[a] The most current version is IEC Standard 62301, "Household electrical appliances–Measurement of standby power", Second Edition, 2011. IEC Standard 62087, "Methods of measurement for the power consumption of audio, video, and related equipment," Second Edition, 2008-2010, is not applicable to this rulemaking. IEC standards may be purchased online at *www.iec.ch*.

Because current product ratings are based on the recently superseded test procedure at appendix J1 (10 CFR 430, subpart B, appendix J1), the definition of baseline units and incremental efficiency levels were established using the current efficiency metrics (MEF and WF) and an understanding of the typical energy use of the products in standby and off modes. As described in Section 5.4.5, DOE then translated each MEF/WF efficiency level into a corresponding IMEF/IWF efficiency level, accounting for the impacts of new provisions in the amended test procedure (appendix J2). The revised energy conservation standards established in this final rule are based on the integrated metrics IMEF and IWF.

5.4.1 Baseline Units

DOE selected baseline units as reference points for each product class. The baseline unit in each product class represents the basic characteristics of equipment in that class. Typically, a baseline unit is a unit that just meets current energy conservation standards and provides basic consumer utility. DOE used the baseline units in the engineering analysis and the LCC and PBP analysis. To determine energy savings and changes in price, DOE compared each higher energy efficiency design option with the baseline unit.

DOE established the baseline level for the top-loading, standard product class based on the 1.26 MEF specified by current Federal energy conservation standards and the 9.5 water factor (WF) requirement established by the Energy Independence and Security Act of 2007 (EISA 2007), which became effective for residential clothes washers manufactured on or after January 1, 2011. For the front-loading, standard product class, DOE applied the former ENERGY STAR level, effective prior to July 2009, to characterize the baseline efficiency level. DOE understands that all commercially available front-loading standard clothes washers have efficiencies that meet or exceed the existing Federal standards and the former ENERGY STAR level of 1.72 MEF and 8.0 WF. For the top-loading, compact product class, DOE defined the baseline efficiency level as 0.77 MEF/14.0 WF based on a survey of products currently available on the market.

For the front-loading, compact product class, DOE defined a baseline efficiency level of 1.60 MEF/8.5 WF, based on an extrapolation of the rated efficiencies of front-loading clothes washers with capacities nearing those that delineate the compact product class (i.e., 1.6 to 3.0 cubic feet). Unlike the other product classes, there are no front-loading, compact products currently on the market that DOE could analyze. A survey of MEF/WF data in the California Energy Commission (CEC) appliance efficiency database reveals that for front-loading clothes washers, unlike for top-loading clothes washers, the MEF relationship with capacity flattens out at capacities less than 3.0 cubic feet, as shown in Figure 5.4.1.

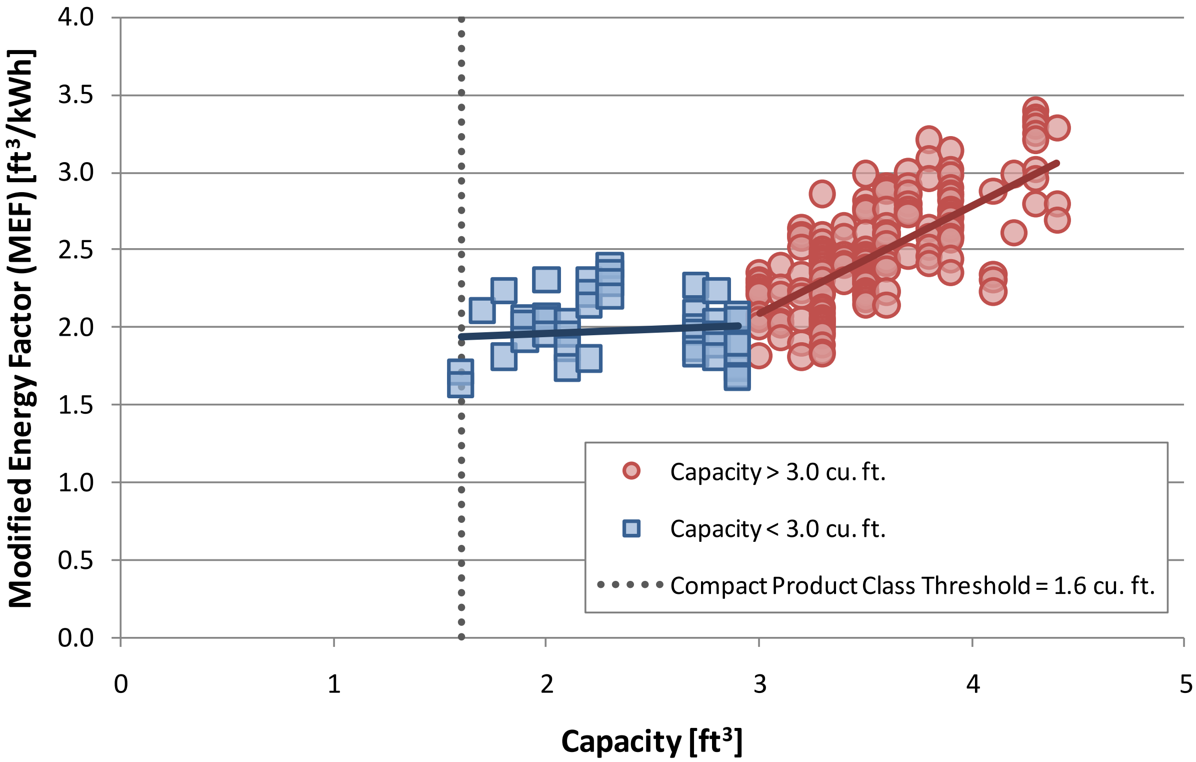

Figure 5.4.1 Relationship between MEF and Capacity for Front-Loading Clothes Washers

By examining the MEF of front-loading clothes washers with capacities just above 1.6 cubic feet, it is evident that the same MEF could likely be achieved for those just below 1.6 cubic feet. DOE believes that any front-loading compact product that might come to market would have a capacity just under 1.6 cubic feet. Among the front-loading clothes washers with capacities less than 3.0 cubic feet, the lowest MEF is 1.63. DOE extrapolated this relationship between MEF and capacity and defined a baseline MEF of 1.60 for the front-loading, compact product class.

DOE performed a similar analysis to define the baseline WF level. Figure 5.4.2 shows the relationship between WF and capacity for front-loading clothes washers.

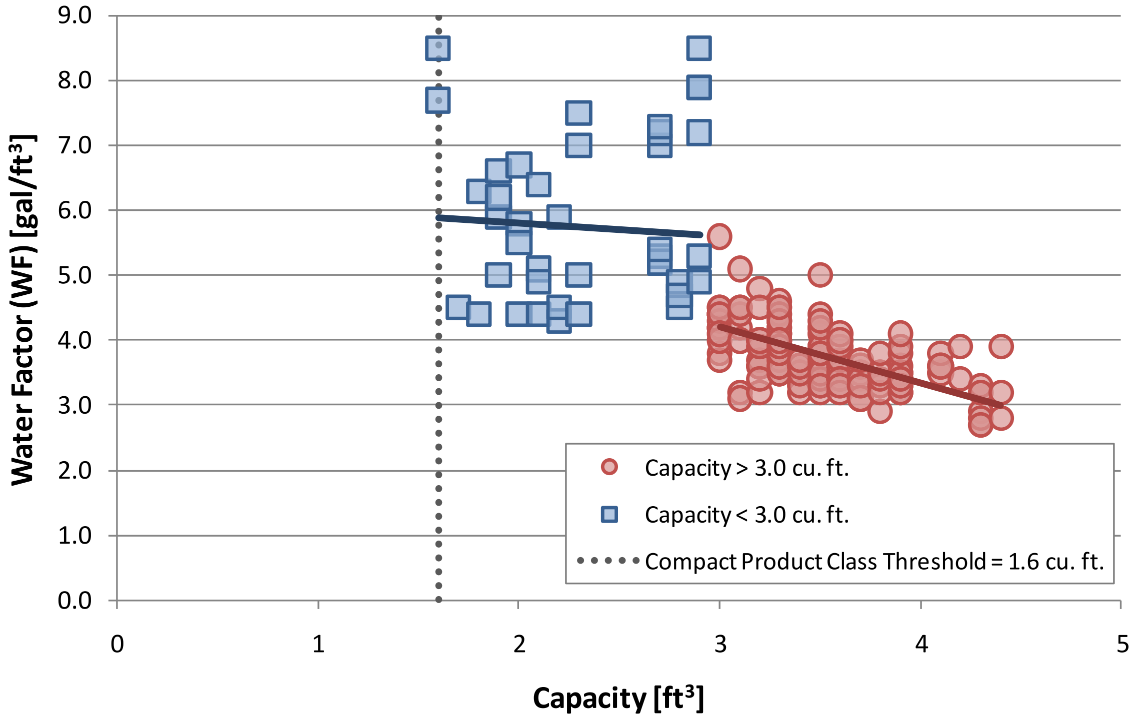

Figure 5.4.2 Relationship between WF and Capacity for Front-Loading Clothes Washers

Unlike the correlation between MEF and capacity, the correlation between WF and capacity is not as strong for front-loading clothes washers less than 3.0 cubic feet. However, DOE noted that the clothes washer with the lowest capacity also has the highest WF (8.5 WF). DOE believes that the same 8.5 WF could be achieved for a front-loading clothes washer just below 1.6 cubic feet. Therefore, DOE defined a baseline WF of 8.5 for the front-loading, compact product class.

Table 5.4.1 lists the baseline active mode efficiencies DOE has selected for all four residential clothes washer product classes.

Table 5.4.1 Clothes Washer Baseline Unit Active Mode Efficiencies

Product Class	**Baseline Efficiency Level Reference Source**	**Baseline Efficiency Level**	
		MEF *(ft^3/kWh)*	**WF** *(gallons/ft^3)*
Top-Loading, Standard	DOE Standard (effective 2011)	1.26	9.5
Front-Loading, Standard	Former ENERGY STAR (pre-July 2009)	1.72	8.0
Top-Loading, Compact	Baseline product on the market	0.77	14.0
Front-Loading, Compact	DOE-estimated baseline level	1.60	8.5

5.4.2 Higher Efficiency Levels

For the top-loading standard and front-loading standard product classes, DOE considered efficiency levels higher than baseline levels based on specifications prescribed by ENERGY

STAR and CEE's Super-Efficient Home-Appliances Initiative. The highest efficiency levels were defined by the maximum available technology that DOE could identify on the market. Where the increments between adjacent efficiency levels were large, DOE added an intermediate "gap-fill" level.

For the top-loading compact product class and front-loading product class, DOE defined higher efficiency levels based on the standard levels proposed in a Joint Petition submitted by groups representing manufacturers and environmental advocates (hereafter referred to as the "Consensus Agreement"). The Consensus Agreement included a proposed set of tiered efficiency standards for top-loading compact clothes washers (effective in 2015 and 2018) and a proposed efficiency standard for front-loading compact clothes washers effective in 2015.

Table 5.4.2 through Figure 5.4.6 provide the active mode efficiency levels and the reference source of each level for the four product classes under consideration.

Table 5.4.2 Top-Loading Standard Clothes Washer Active Mode Efficiency Levels, Based on MEF and WF

Level	**Efficiency Level Reference Source**	**Efficiency Level**	
		MEF *(ft^3/kWh/cycle)*	**WF** *(gal/cycle/ft^3)*
Baseline	DOE Standard	1.26	9.5
EL 1	Gap Fill	1.40	9.5
EL 2	Former ENERGY STAR (pre- 2009)	1.72	8.0
EL 3	Former ENERGY STAR (pre-2011)	1.80	7.5
EL 4	Current ENERGY STAR (Jan 2011)	2.00	6.0
EL 5	Previous Max Available (at time of Framework Document)	2.26	4.5
EL 6	Current Max Available	2.47	3.6

Table 5.4.3 Front-Loading Standard Clothes Washer Active Mode Efficiency Levels, Based on MEF and WF

Level	**Efficiency Level Reference Source**	**Efficiency Level**	
		MEF *(ft^3/kWh/cycle)*	**WF** *(gal/cycle/ft^3)*
Baseline	Former ENERGY STAR (pre-July 2009)	1.72	8.0
EL 1	Former ENERGY STAR (pre-Jan 2011)	1.80	7.5
EL 2	Current ENERGY STAR (Jan 2011), also CEE Tier 1	2.00	6.0
EL 3	CEE Tier 2	2.20	4.5
EL 4	Gap Fill, also CEE Tier 3*	2.40	4.2*
EL 5	Gap Fill	2.60	3.8
EL 6	Max Available	2.89	3.2

* CEE Tier 3 currently specifies a maximum water factor of 4.0. The water factor of 4.2 for this gap fill level was selected before the current CEE Tier 3 specification was announced.

Table 5.4.4 Efficiency Levels for Top-Loading Compact Residential Clothes Washer Final Analysis

Level	Efficiency Level Description	Efficiency Level	
		MEF *(ft^3/kWh/cycle)*	**WF** *(gal/cycle/ft^3)*
Baseline	Baseline product on the market	0.77	14.0
1	Consensus Agreement (2015 Proposed Standard)	1.26	14.0
2	Consensus Agreement (2018 Proposed Standard)	1.81	11.6

Table 5.4.5 Efficiency Levels for Front-Loading Compact Residential Clothes Washer Final Analysis

Level	Efficiency Level Description	Efficiency Level	
		MEF *(ft^3/kWh/cycle)*	**WF** *(gal/cycle/ft^3)*
Baseline	DOE-estimated baseline level	1.60	8.5
1	Consensus Agreement (2015 Proposed Standard)	1.72	8.0

For top-loading standard clothes washers, DOE analyzed six efficiency levels beyond the baseline, as listed in **Table** 5.4.2. These levels were based on the previous and current ENERGY STAR levels, some of which correspond to the Consortium for Energy Efficiency (CEE) Residential Clothes Washer Initiative efficiency tiers, and the maximum level that is currently commercially available (which DOE used as a proxy for max-tech) as determined from data contained within the California Energy Commission (CEC) and ENERGY STAR product databases. DOE also added a gap-fill level to span the large difference in efficiency between the baseline and former ENERGY STAR (pre-2009) level.

For front-loading standard residential clothes washers, DOE analyzed six efficiency levels beyond the baseline, as listed in **Table** 5.4.3. These levels were based on the former and current ENERGY STAR levels, the CEE Residential Clothes Washer Initiative efficiency tiers, and maximum levels that are currently commercially available. Two gap-fill levels were added between the CEE Tier 2 and the maximum available level. DOE determined the max-tech level based on an extensive market survey, which suggests that the max tech unit's combination of high MEF and low WF represents the best-in-class balance between MEF and WF.

As described above, DOE defined higher efficiency levels for the top-loading compact and front-loading product classes based on the standard levels proposed in the Consensus Agreement.

5.4.3 Maximum Technologically Feasible Efficiency Levels

Under EPCA, DOE is required to consider the maximum technologically feasible level ("max-tech"). DOE determines max-tech levels based on technologies that are either commercially available or have been demonstrated as working prototypes. If the max-tech design meets DOE's screening criteria, DOE considers the design in further analysis. DOE also considers consumer utility and availability of features, which may be met by a niche product, as required by EPCA.

DOE identified the max-tech levels for top-loading standard and front-loading standard residential clothes washers based on the maximum performance of products currently on the market in the United States. DOE considered several models in each product class to determine max-tech values that best represent optimal performance of MEF and WF for clothes washers on the market. DOE determined, based on comments from interested parties, that a high MEF and low WF are not necessarily correlated, and therefore, a max-tech level based on the highest MEF and lowest WF is not realistic (i.e., a residential clothes washer with the highest possible MEF may not achieve the lowest possible WF, and *vice versa*). Therefore, DOE selected residential clothes washers currently available on the market that exhibit a balance of high MEF and low WF to represent the max-tech levels.

For top-loading compact clothes washers, DOE used the 2018 standard level proposed in the Consensus Agreement as the max-tech level, as described previously. For front-loading compact clothes washers, DOE used the 2015 standard level proposed in the Consensus Agreement as the max-tech level. Based on energy and water consumption modeling using a design option approach, DOE believes that these max-tech levels correspond to the maximum technologically feasible efficiency levels for the top-loading compact and front-loading compact product classes.

Finally, DOE has observed that the max-tech units on the market use a combination of significantly reduced water volumes, reduced water temperatures, extended cycle times, and extremely high spin speeds. DOE is not aware of any additional design options that could be used to increase the efficiency beyond the max-tech levels without causing potential negative effects on consumer utility. Nor is DOE aware of any working prototype clothes washers that exceed the efficiency levels of the max-tech units on the market in the United States. Therefore, DOE believes the "max available" efficiency levels for residential clothes washers correspond to the maximum technologically feasible efficiency levels.

5.4.4 Standby Mode and Off Mode Power

DOE measured standby and off mode energy use of residential clothes washers in its sample of reverse-engineered units. The results of the standby and off mode measurements are shown in Table 5.4.6 below. DOE performed these tests according to the provisions in IEC Standard 62301 First Edition[b], including Section 5, Paragraph 5.1, note 1, which instructs to allow sufficient time for the product to reach the lower power state before proceeding with the test measurement. Some of clothes washers in the test sample with electromechanical controls did not consume any power when the units were plugged in and not in active mode, or once a

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[b] IEC Standard 62301 First Edition was the most current version at the time the engineering analysis was conducted. The Second Edition was published January 27, 2011 and contains revisions affecting the definitions and measurement methodology of standby and off-mode power. However, DOE believes that the methodology of the Second Edition would produce nearly identical standby power consumption measurements.

wash cycle had completed. With no status or information displays activated and no reactivation possible by remote switch, internal sensor, or timer, such units meet the definition of operation in off mode. DOE also noted that for some units with electronic controls, after a period of user inactivity (generally between 5 and 10 minutes), the display turns off and the power consumption reverts to the power consumption seen in the plugged in and off condition. For this reason, DOE believes that the lowest power consumption state for units with electronic controls provides for the most representative standby/off mode energy use.

Table 5.4.6 Clothes Washer Standby and Off Mode Power Measurements

Product Class	Test Unit	Rated MEF *(ft^3/kWh)*	Control Type	Power Supply Type	Power Consumption *(W)*	Lowest Power Mode
Top-Loading, Standard	1	1.35	Electromechanical	N/A	0.00	Off
	2	1.48	Electromechanical	N/A	0.00	Off
	3	1.76	Electromechanical	N/A	0.05	Standby
	4	1.82	Electronic	Switch-mode	1.16	Standby
	5	2.11	Electronic	Switch-mode	1.15	Standby
	6	2.25	Electronic	Switch-mode	1.67	Standby
Front-Loading, Standard	7	1.82	Electronic	Switch-mode	0.77	Standby
	8	2.13	Electronic	Switch-mode	1.60	Standby
	9	2.2	Electronic	Transformerless	0.01	Standby
	10	2.2	Electronic	Switch-mode	0.44	Standby
	11	2.38	Electronic	Switch-mode	1.60	Standby
	12	2.44	Electronic	Transformerless	0.01	Standby
	13	2.64	Electronic	Switch-mode	1.65	Standby
	14	2.71	Electronic	Transformerless	0.08	Standby
	15	2.89	Electronic	Switch-mode	0.01	Standby

The models in this DOE test sample with electronic controls incorporated switch-mode and transformerless power supplies. The power consumption for units with switch-mode power supplies ranged from 0.44 to 1.67 W. The power consumption for units with transformerless power supplies ranged from 0.01 to 0.08 W.

None of the models in this test sample used a conventional linear power supply, which DOE believes would represent a baseline design option with higher power consumption than a switch-mode power supply. Based on tests that DOE performed on residential dryers with conventional linear power supplies, DOE believes a clothes washer with a conventional linear power supply would consume approximately 2.3 W in standby mode. DOE estimated this baseline power level by scaling the power consumption measured for a baseline dryer according to the size of the transformer required for a residential clothes washer. (5VA transformer for clothes dryers, and 30VA transformer for clothes washers).

Based on its limited testing, DOE defined three standby power levels for analysis, shown in Table 5.4.7. DOE observed that both top-loading clothes washers and front-loading clothes washers share many of the same hardware components within the electronic controls; therefore, DOE believes that these standby power levels are the same for both top-loading and front-loading residential clothes washers. DOE defined each level based on the highest standby power consumption observed for each configuration.

Table 5.4.7 Residential Clothes Washer Standby Power Levels

Level	Standby Power Source	Power Input *(W)*
Baseline	DOE Test Data and Analysis	2.3
SL 1	DOE Test Data	1.7
SL 2	DOE Test Data (Max-Tech)	0.08

The baseline standby power level is associated with a linear regulated control board power supply. SL 1 is associated with changing from a conventional power supply to a switch-mode power supply. For SL 2, a transformerless drop-cap power supply applied to the baseline linear power supply enables a microcontroller to remain on at all times while disabling the main power supply whenever the clothes washer is “asleep”. The control logic monitors the clothes washer for key-presses, door openings, etc., and when user activity is detected, the logic activates the main power supply.

DOE recognizes that many top-loading clothes washers that just meet the current Federal energy conservation standards for MEF use electromechanical controls, which consume no standby power. Baseline standby power of 2.3 W is incorporated at the first MEF level for which electronic controls are required in order to achieve higher efficiency. For front-loading clothes washers, virtually all units at the baseline efficiency level incorporate electronic controls, and thus the baseline standby power level of 2.3 W is incorporated at the baseline MEF level. At higher MEF levels for both product classes, DOE believes that standby power improvements would be used at the lowest efficiency level where they would be cost effective. A summary of the incremental costs, and the methodology used to determine them, can be found in section 5.6.4. Table 5.4.8 and Table 5.4.9 show the standby power levels associated with each MEF efficiency level for top-loading standard and front-loading standard clothes washers.

Table 5.4.8 Standby Power and Associated MEF Levels for Top-Loading Standard Clothes Washers

Level	Efficiency Level Description	MEF *(ft^3/kWh)*	WF *(gal/ft^3)*
Baseline	DOE Standard + 0 W Standby	1.26	9.5
EL 1	Gap Fill + 0 W Standby	1.40	9.5
EL 2	Former ENERGY STAR (pre- 2009) + 0 W Standby	1.72	8.0
EL 3	Former ENERGY STAR (pre-2011) + 2.3 W Standby	1.80	7.5
EL 4	Former ENERGY STAR (pre-2011) + 1.7 W Standby	1.80	7.5
EL 5	Former ENERGY STAR (pre-2011) + 0.08 W Standby	1.80	7.5
EL 6	Current ENERGY STAR (Jan 2011) + 0.08 W Standby	2.00	6.0
EL 7	Max Available (at time of Framework Document) + 0.08 W Standby	2.26	4.5
EL 8	Current Max Available + 0.08 W Standby	2.47	3.6

Table 5.4.9 Standby Power and Associated MEF Levels for Front-Loading Clothes Washers

Level	Efficiency Level Description	MEF *(ft^3/kWh)*	WF *(gal/ft^3)*
Baseline	Former ENERGY STAR (pre-2009) + 2.3 W Standby	1.72	8.0
EL 1	Former ENERGY STAR (pre-2009) + 1.7 W Standby	1.72	8.0
EL 2	Former ENERGY STAR (pre-2009) + 0.08 W Standby	1.72	8.0
EL 3	Former ENERGY STAR (pre-2011) + 0.08 W Standby	1.80	7.5
EL 4	Current ENERGY STAR (Jan 2011) + 0.08 W Standby	2.00	6.0
EL 5	CEE Tier 2 + 0.08 W Standby	2.20	4.5
EL 6	Gap Fill + 0.08 W Standby	2.40	4.2
EL 7	Gap Fill + 0.08 W Standby	2.60	3.8
EL 8	Max Available + 0.08 W Standby	2.89	3.2

Because DOE used the standard levels proposed in the Consensus Agreement as the basis for the higher efficiency levels for the top-loading compact and front-loading product classes, DOE did not associate standby power levels with any of the higher efficiency levels for these product classes.

5.4.5 Integrated Efficiency Metrics

As described earlier, the amended test procedure at appendix J2 incorporates standby and off mode power measurements as well as number of other revisions that affect the IMEF and IWF calculations. DOE translated each MEF/WF efficiency level into a corresponding IMEF/IWF efficiency level to account for the impacts of new provisions in appendix J2.

Table 5.4.10 shows the major revisions included in the amended test procedure that significantly affect the calculated efficiency metrics.

Table 5.4.10 Revisions to the Clothes Washer Test Procedure that Significantly Affect Efficiency Metrics

Factors Affecting MEF / IMEF	Appendix J1	Appendix J2
Capacity measurement	For top-loading clothes washers: Innermost diameter of the tub cover. (Defined as "Fill Level 3" in DOE guidance document[c])	For top-loading clothes washers: Uppermost edge of the rotating portion, including any balance ring. (Defined as "Fill Level 2" in DOE guidance document)
Temperature Use Factors (TUF)	"Warm Rinse" included as an incremental featured added to a Warm Wash / Cold Rinse cycle.	Warm Wash / Warm Rinse cycle included as a complete, unique cycle.
Remaining Moisture Content (RMC)	Calculation performed using maximum test load weight corresponding to "Fill Level 3" capacity	Calculation performed using maximum test load weight corresponding to "Fill Level 2" capacity
Dryer energy calculation	Based on Load Adjustment Factor (LAF) of 0.52 multiplied by maximum test load weight	Based on weighted average load size according to existing Load Usage Factors (LUF).
Dryer Usage Factor (DUF)	DUF = 0.84	DUF = 0.91
Standby and off mode power	Not included.	Included in calculation based on 8,465 hours in standby/off mode, apportioned over all active mode cycles.
Number of annual cycles	392; Not included in any test procedure calculations.	295; Included as the basis for standby/off mode hours.
Factors Affecting WF / IWF		
Capacity measurement	See above.	See above.
Water Consumption	Based on water usage of Cold Wash / Cold Rinse cycles only.	Based on weighted average of water usage of all Wash / Rinse temperature combinations

IMEF is calculated as the clothes washer capacity in cubic feet divided by the sum, expressed in kWh, of the total weighted per-cycle hot water energy consumption, the total weighted per-cycle machine electrical energy consumption, the per-cycle energy consumption for removing moisture from a test load, and the per-cycle standby and off mode energy consumption. IWF is calculated as the total weighted per-cycle water consumption for all wash cycles, expressed in gallons per cycle; divided by the clothes container capacity in cubic feet.

To perform the efficiency metric translations, DOE tested a wide range of top-loading and front-loading clothes washers according to both appendix J1 and appendix J2. Based on these tests, DOE developed conversion formulas to relate MEF to IMEF, and WF to IWF. The conversion formulas take into account all the changes to the test procedure listed in Table 5.4.10. Therefore, a clothes washer that currently meets a given MEF/WF level as tested under appendix J1 would subsequently meet the corresponding IMEF/IWF level as tested under appendix J2.

[c] DOE issued guidance in May 2010 on what is considered the clothes container for purposes of measuring clothes container capacity. The Interpretive Rule is available at the residential clothes washer rulemaking website, http://www1.eere.energy.gov/buildings/appliance_standards/residential/clothes_washers.html

Because the IMEF calculation is affected by the measured standby power level, DOE developed separate conversion formulas for each of the standby power levels identified in Table 5.4.7. The appropriate conversion formula was then applied to each efficiency level in Table 5.4.8 and Table 5.4.9 according to the standby power associated with each level.

5.4.5.1 Top-Loading, Standard Product Class

Figure 5.4.3 and Figure 5.4.4 show the MEF/IMEF and WF/IWF linear correlation curves, respectively, from which the conversion formulas were derived for top-loading standard clothes washers. Each data point represents the test results for a single clothes washer in the test sample.

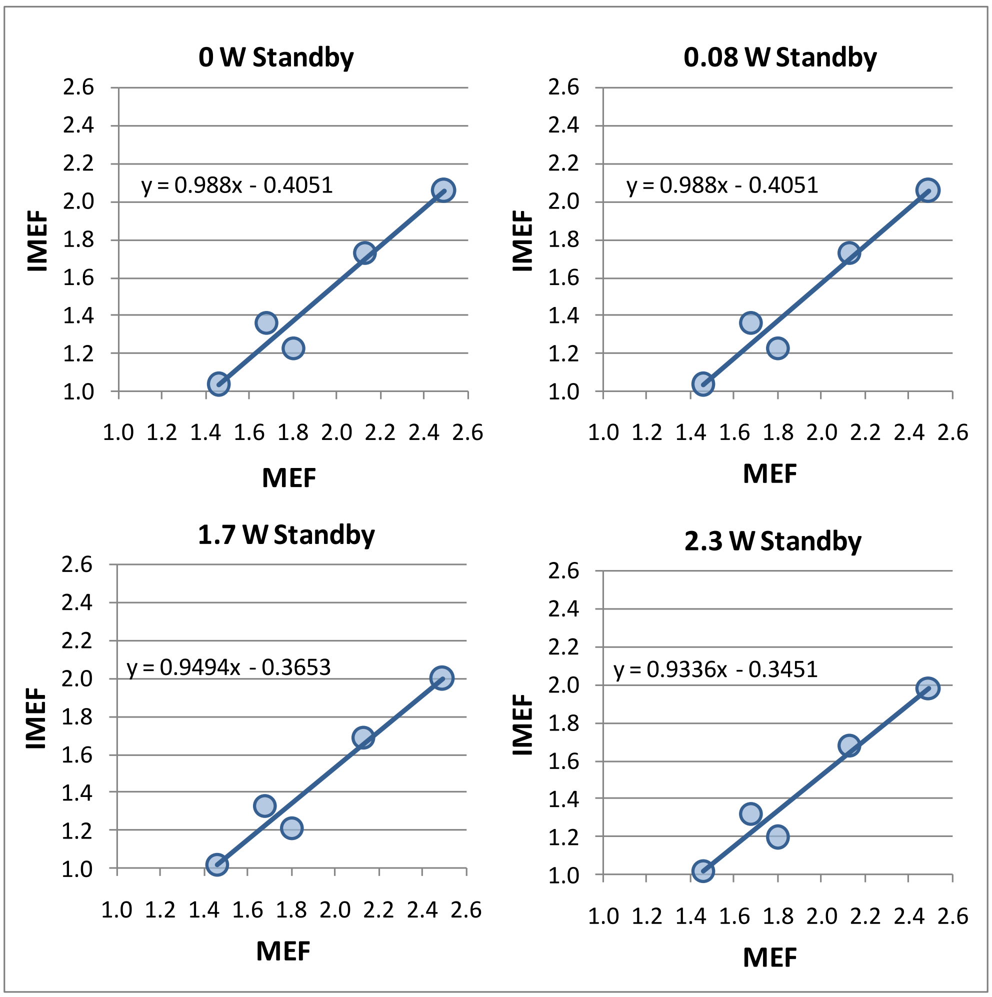

Figure 5.4.3 MEF to IMEF Conversion Curves for Top-Loading Standard Residential Clothes Washers

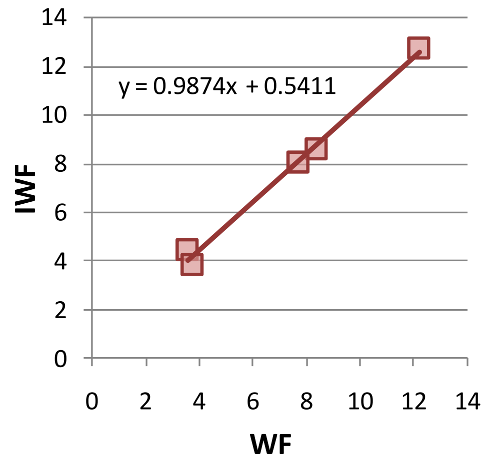

Figure 5.4.4 WF to IWF Conversion Curve for Top-Loading Standard Residential Clothes Washers

Table 5.4.11 shows the integrated efficiency levels used in the final analysis for top-loading standard clothes washers, based on these conversion formulas.

Table 5.4.11 Integrated Efficiency Levels for Top-Loading Standard Residential Clothes Washers

Level	Efficiency Level Description	Efficiency Level – Appendix J1		Integrated Efficiency Level – Appendix J2	
		MEF *(ft^3/kWh/ cycle)*	**WF** *(gal/cycle/ ft^3)*	**IMEF** *(ft^3/kWh/ cycle)*	**IWF** *(gal/cycle/ ft^3)*
Baseline	DOE Standard + 0 W Standby	1.26	9.5	0.84	9.9
EL 1	Gap Fill + 0 W Standby	1.40	9.5	0.98	9.9
EL 2	Former ENERGY STAR (pre- 2009) + 0 W Standby	1.72	8.0	1.29	8.4
EL 3	Former ENERGY STAR (pre-2011) + 2.3 W Standby	1.80	7.5	1.34	7.9
EL 4	Former ENERGY STAR (pre-2011) + 1.7 W Standby	1.80	7.5	1.34	7.9
EL 5	Former ENERGY STAR (pre-2011) + 0.08 W Standby	1.80	7.5	1.37	7.9
EL 6	Current ENERGY STAR (Jan 2011) + 0.08 W Standby	2.00	6.0	1.57	6.5
EL 7	Max Available (at time of Framework Document) + 0.08 W Standby	2.26	4.5	1.83	5.0
EL 8	Current Max Available + 0.08 W Standby	2.47	3.6	2.04	4.1

5.4.5.2 **Front-Loading, Standard Product Class**

Figure 5.4.5 and Figure 5.4.6 show the MEF/IMEF and WF/IWF linear correlation curves, respectively, from which the conversion formulas were derived for front-loading standard clothes washers. Each data point represents the test results for a single clothes washer in the test sample.

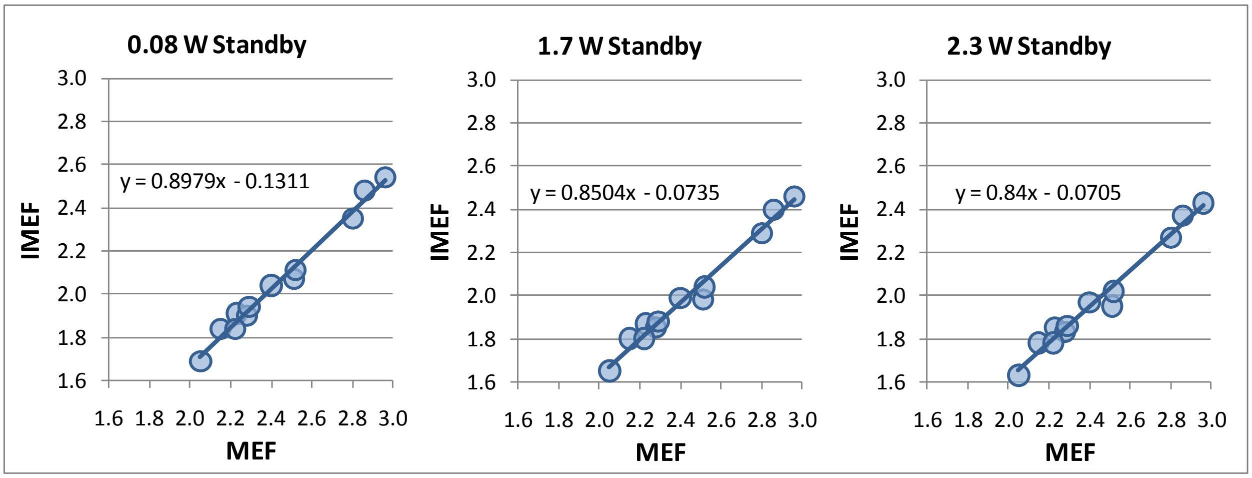

Figure 5.4.5 MEF to IMEF Conversion Curves for Front-Loading Washers

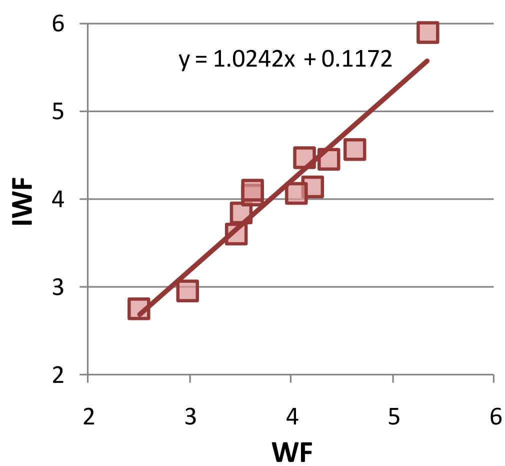

Figure 5.4.6 WF to IWF Conversion Curve for Front-Loading Standard Residential Clothes Washers

Table 5.4.12 shows the integrated efficiency levels used in the final analysis for front-loading standard clothes washers, based on these conversion formulas.

Table 5.4.12 Integrated Efficiency Levels for Front-Loading Standard Residential Clothes Washers

Level	Efficiency Level Description	Efficiency Level – Appendix J1		Integrated Efficiency Level – Appendix J2	
		MEF *(ft^3/kWh/ cycle)*	**WF** *(gal/cycle/ ft^3)*	**IMEF** *(ft^3/kWh/ cycle)*	**IWF** *(gal/cycle/ ft^3)*
Baseline	Former ENERGY STAR (pre- 2009) + 2.3 W Standby	1.72	8.0	1.37	8.3
EL 1	Former ENERGY STAR (pre- 2009) + 1.7 W Standby	1.72	8.0	1.39	8.3
EL 2	Former ENERGY STAR (pre- 2009) + 0.08 W Standby	1.72	8.0	1.41	8.3
EL 3	Former ENERGY STAR (pre-2011) + 0.08 W Standby	1.80	7.5	1.49	7.8
EL 4	Current ENERGY STAR (Jan 2011) + 0.08 W Standby	2.00	6.0	1.66	6.3
EL 5	CEE Tier 2 + 0.08 W Standby	2.20	4.5	1.84	4.7
EL 6	Gap Fill + 0.08 W Standby	2.40	4.2	2.02	4.4
EL 7	Gap Fill + 0.08 W Standby	2.60	3.8	2.20	4.0
EL 8	Max Available + 0.08 W Standby	2.89	3.2	2.46	3.4

5.4.5.3 Top-Loading, Compact Product Class

DOE conducted an alternate analysis for the top-loading compact product class because of the limited number of top-loading compact clothes washers available on the market for testing. DOE conducted testing on several compact top-loading washers and determined the typical energy and water consumption characteristics of a baseline model. Then, using the design option approach supplemented with information obtained through manufacturer interviews, DOE modeled the energy and water savings that would be achieved by implementing specific design options required to achieve the higher efficiency levels. DOE modeled the energy and water consumption according to the provisions of both appendix J1 and appendix J2, and used these results to develop the MEF/IMEF and WF/IWF correlation curves.

Table 5.4.13 shows the results of the energy consumption modeling at each efficiency level using appendix J1. Table 5.4.14 shows the results of the energy consumption modeling at each efficiency level using appendix J2. Table 5.4.15 shows the results of the water consumption modeling at each efficiency level using appendix J1. Table 5.4.16 shows the results of the water consumption modeling at each efficiency level using appendix J2.

Table 5.4.13 Energy Consumption Modeling of Top-Loading Compact Product Class Using Appendix J1

Efficiency Level	Capacity (ft^3)	Electrical Energy (kWh/cycle)	Hot Water Energy (kWh/cycle)	Dryer Energy (kWh/cycle)	MEF (ft^3/kWh/cycle)
Baseline	1.50	0.30	0.89	0.76	0.77
Level 1	1.59	0.30	0.21	0.76	1.26
Level 2	1.59	0.11	0.19	0.58	1.81

Table 5.4.14 Energy Consumption Modeling of Top-Loading Compact Product Class Using Appendix J2

Efficiency Level	Capacity (ft^3)	Electrical Energy (kWh/cycle)	Hot Water Energy (kWh/cycle)	Dryer Energy (kWh/cycle)	Standby Energy (kWh/cycle)	IMEF (ft^3/kWh/ cycle)
Baseline	1.50	0.30	0.89	1.35	0.00	0.59
Level 1	1.59	0.30	0.19	1.37	0.00	0.86
Level 2	1.59	0.11	0.19	1.01	0.07	1.15

Table 5.4.15 Water Consumption Modeling of Top-Loading Compact Product Class Using Appendix J1

Efficiency Level	Capacity (ft^3)	Water Consumption (gal/cycle)	WF (gal/cycle/ft^3)
Baseline	1.50	21.0	14.0
Level 1	(same as Baseline)		14.0
Level 2	1.59	18.4	11.6

Table 5.4.16 Water Consumption Modeling of Top-Loading Compact Product Class Using Appendix J2

Efficiency Level	Capacity (ft^3)	Water Consumption (gal/cycle)	IWF (gal/ cycle/ft^3)
Baseline	1.50	21.6[d]	14.4[e]
Level 1	(same as Baseline)		14.4[f]
Level 2	1.59	19.1	12.0

[d] This number was incorrectly reported as 22.4 in the previous version of this chapter.
[e] This number was incorrectly reported as 14.9 in the previous version of this chapter.
[f] This number was incorrectly reported as 14.9 in the previous version of this chapter.

Table 5.4.17 shows the integrated efficiency levels used in the final analysis for top-loading compact clothes washers, based on the results of the energy and water consumption modeling.

Table 5.4.17 Integrated Efficiency Levels for Top-Loading Compact Residential Clothes Washers

Level	Efficiency Level Description	Efficiency Level – Appendix J1		Integrated Efficiency Level – Appendix J2	
		MEF *(ft^3/kWh/ cycle)*	**WF** *(gal/cycle/ ft^3)*	**IMEF** *(ft^3/kWh/ cycle)*	**IWF** *(gal/cycle/ ft^3)*
Baseline	Baseline product on the market	0.77	14.0[g]	0.59	14.4
EL 1	Consensus Agreement (2015 Proposed Standard)	1.26	14.0[h]	0.86	14.4
EL 2	Consensus Agreement (2018 Proposed Standard)	1.81	11.6[i]	1.15	12.0

5.4.5.4 Front-Loading, Compact Product Class

DOE is unaware of any compact front-loading clothes washers currently on the market in the United States. Therefore, DOE estimated the IMEF conversion formula based on expected product and performance characteristics for baseline models within that product class. Table 5.4.18 lists the expected product characteristics of a baseline compact front-loading clothes washer.

Table 5.4.18 Expected Product Characteristics of a Baseline Compact Front-Loading Clothes Washer

Feature	Expected Product Characteristics
Capacity	1.5 – 1.59 ft^3
Remaining Moisture Content	45% –50%
Control System	Electronic controls with baseline-level standby power consumption
Fill Level Control	Automatic fill using mechanical pressure sensor
Warm Rinse	Unavailable

Based on the capacities of all clothes washers in the CEC database, DOE believes that 1.5 cubic feet is an approximate lower bound on capacity that can be expected for compact front-loading clothes washers.

DOE further believes that a remaining moisture content (RMC) of 45–50 percent conservatively represents an appropriate upper bound for compact front-loading clothes washers with 1.5–1.6 cubic feet of capacity. DOE derived this estimate from three independent sources of information First, a single compact front-loading unit tested by CSA International has an RMC of 46 percent according to the Canadian clothes washer test procedure, C360-03, which is largely

[g] This number was incorrectly reported as 0.59 in the previous version of this chapter
[h] This number was incorrectly reported as 0.86 in the previous version of this chapter
[i] This number was incorrectly reported as 1.15 in the previous version of this chapter

similar to the DOE clothes washer test procedure at appendix J1[j]. Second, a trend line of RMC versus capacity for clothes washers in the CEC database indicates that the maximum expected RMC for compact-size units lies within a range of 40–50 percent, as shown by the shaded circle in Figure 5.4.7. Third, an analysis by DOE of the tub geometry of a front-loading clothes washer with 1.5 cubic feet capacity indicates that the clothing inside the wash tub would experience a maximum of around 150 g's during the spin cycle. This would correspond to an RMC of approximately 45 to 50 percent.

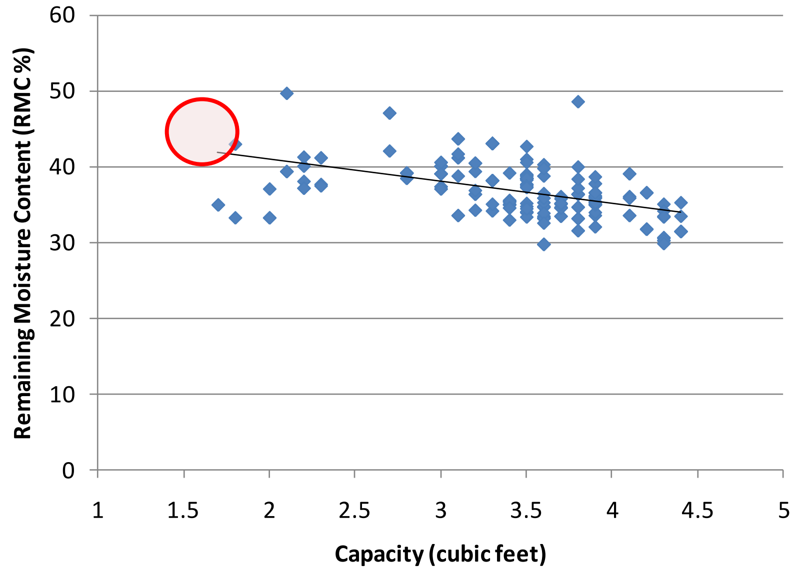

Figure 5.4.7 RMC as a Function of Capacity for Front-Loading Clothes Washers in the CEC Database, 2008-2011

Similar to the analysis for the top-loading compact product class, DOE conducted an alternate analysis for the front-loading compact product class. Using a design option approach, and extrapolating test results from the front-loading standard product class, DOE modeled the energy and water savings that would be achieved by implementing specific design options required to achieve the higher efficiency levels. DOE modeled the energy and water consumption according to the provisions of both appendix J1 and appendix J2, and used these results to develop the MEF/IMEF and WF/IWF correlation curves.

Table 5.4.19 shows the results of the energy and water consumption modeling at each efficiency level using appendix J1. Table 5.4.20 shows the results of the energy and water consumption modeling at each efficiency level using appendix J2.

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[j] RMC values were derived from reported values of capacity, MEF, and energy consumption. Test report from CSA International available at http://directories.csa-international.org/xml_transform.asp?xml=certxml\244824-8802-01.xml&xsl=xsl/certrec.xsl

Table 5.4.19 Energy and Water Consumption Modeling of Front-Loading Compact Product Class Using Appendix J1

Efficiency Level	Capacity (ft^3)	Electrical Energy (kWh/cycle)	Hot Water Energy (kWh/cycle)	Dryer Energy (kWh/cycle)	Water Consumption (gal/cycle)	MEF (ft^3/kWh/cycle)	WF (gal/cycle/ft^3)
Baseline	1.50	0.10	0.27	0.57	12.8	1.60	8.8
Level 1	1.50	0.10	0.20	0.57	12.0	1.72	8.0

Table 5.4.20 Energy Consumption Modeling of Front-Loading Compact Product Class Using Appendix J2

Efficiency Level	Capacity (ft^3)	Electrical Energy (kWh/cycle)	Hot Water Energy (kWh/cycle)	Dryer Energy (kWh/cycle)	Standby Energy (kWh/cycle)	Water Consumption (gal/cycle)	IMEF (ft^3/kWh/ cycle)	IWF (gal/cycle/ ft^3)
Baseline	1.50	0.10	0.27	1.02	0.07	13.2	1.03	8.8
Level 1	1.50	0.10	0.20	1.02	0.00	12.5	1.13	8.3

Table 5.4.21 shows the integrated efficiency levels used in the final analysis for front-loading compact clothes washers, based on the results of the energy and water consumption modeling.

Table 5.4.21 Integrated Efficiency Levels for Front-Loading Compact Residential Clothes Washers

		Efficiency Level – Appendix J1		Integrated Efficiency Level – Appendix J2	
Level	**Efficiency Level Description**	**MEF** *(ft^3/kWh/ cycle)*	**WF** *(gal/cycle/ ft^3)*	**IMEF** *(ft^3/kWh/ cycle)*	**IWF** *(gal/cycle/ ft^3)*
Baseline	DOE-estimated baseline level	1.60	8.5	1.03	8.8
EL 1	Consensus Agreement (2015 Proposed Standard)	1.72	8.0	1.13	8.3

5.5 METHODOLOGY OVERVIEW

DOE used data submitted by AHAM (see appendix 5-A and 5-B of this TSD) as one source of cost information for the engineering analysis. AHAM provided DOE with aggregated incremental manufacturing cost data from its member companies. DOE conducted an independent review of the AHAM data using several methods and data sources. To gain a better understanding of the data submitted by member companies and to be able to relate the costs of improving efficiency to discrete or system-level technologies, DOE reviewed the TSD from the previous rulemaking and conducted interviews with residential clothes washer manufacturers. DOE also performed detailed product teardowns and cost modeling on multiple clothes washer models spanning a range of efficiencies to generate cost-efficiency curves. These cost-efficiency relationships were compared to the AHAM data for validation. Finally, DOE conducted standby power testing, as well as detailed energy performance testing at an independent laboratory and internally to gain insights into energy performance in active, standby, and off modes.

5.5.1 AHAM Data Request

In support of this rulemaking effort, DOE requested incremental cost data from AHAM for residential clothes washers. The data represent the average incremental production cost to improve a baseline unit to a specified efficiency level. In addition, DOE requested shipments, shipment-weighted average efficiency, and market share efficiency data. A discussion of the data provided by AHAM is included in section 5.6.1.

5.5.2 Manufacturer Interviews

DOE understands that there is variability among manufacturers in baseline units, design strategies, and cost structures. To better understand and explain these variances, DOE conducted manufacturer interviews. These confidential interviews provided a deeper understanding of the various combinations of technologies used to increase residential clothes washer efficiency, and their associated manufacturing costs. Sample questions asked during the interviews are contained in appendix 5C.

During the interviews, DOE also gathered information about the capital expenditures required to increase the efficiency of the baseline units to various efficiency levels (*i.e.*, conversion capital expenditures by efficiency or energy-use level). The interviews provided information about the size and the nature of the capital investments. DOE also requested information about the depreciation method used to expense the conversion capital. The manufacturer impact analysis in chapter 12 includes a discussion of this information obtained during manufacturer interviews.

5.5.3 Product Teardown Methodology

Other than obtaining detailed manufacturing costs directly from a manufacturer, the most accurate method for determining the production cost of a product is to disassemble representative units piece-by-piece and estimate the material, labor, and overhead costs associated with each component using a process commonly called a physical teardown. A supplementary method, called a catalog teardown, uses published manufacturer catalogs and supplementary component data to estimate the major physical differences between a product that has been physically disassembled and another similar product. DOE performed physical teardown analysis on both top-loading and front-loading clothes washers. The teardown methodology is explained in the following sections.

5.5.3.1 **Selection of Units**

DOE generally adopts the following criteria for selecting units for teardown analysis:

- The selected products should span the full range of efficiency levels for each product class under consideration;

- Within each product class, the selected products should, if possible, come from the same manufacturer and belong to the same product platform;
- The selected products should, if possible, come from manufacturers with large market shares in that product class, although the highest efficiency products are chosen irrespective of manufacturer; and
- The selected products should have non-efficiency-related features that are the same as, or similar to, features of other products in the same class and at the same efficiency level.

5.5.3.2 **Generation of Bill of Materials**

The end result of each teardown is a structured bill of materials (BOM), which describes each product part and its relationship to the other parts, in the estimated order of assembly. The BOMs describe each fabrication and assembly operation in detail, including the type of value—added equipment needed (*e.g.*, stamping presses, injection molding machines, spot-welders, etc.) and the estimated cycle times associated with each conversion step. The result is a thorough and explicit model of the production process.

Materials in the BOM are divided between raw materials that require conversion steps to be made ready for assembly, while purchased parts are typically delivered ready for installation. The classification into raw materials or purchased parts is based on DOE's previous industry experience, recent information in trade publications, and discussions with original equipment manufacturers (OEMs). For purchased parts, the purchase price is based on volume-variable price quotations and detailed discussions with suppliers.

For parts fabricated in-house, the prices of the underlying "raw" metals (*e.g.,* tube, sheet metal) are estimated on the basis of 5-year averages to smooth out spikes in demand. Other "raw" materials such as plastic resins, insulation materials, etc. are estimated on a current-market basis. The costs of raw materials are based on manufacturer interviews, quotes from suppliers, secondary research, and by subscriptions to publications including the American Metals Market (AMM).[k] Past price quotes are indexed using applicable Bureau of Labor Statistics producer price index tables as well as AMM monthly data.

5.5.3.3 **Cost Structure of the Spreadsheet Models**

The manufacturing cost assessment methodology used is a detailed, component-focused technique for rigorously calculating the manufacturing cost of a product (direct materials, direct labor and some overhead costs). Figure 5.5.1 shows the three major steps in generating the manufacturing cost.

[k] For information on American Metals Market, please visit: *www.amm.com*.

Figure 5.5.1 Manufacturing Cost Assessment Stages

The first step in the manufacturing cost assessment was the creation of a complete and structured BOM from the disassembly of the units selected for teardown. The units were dismantled, and each part was characterized according to weight, manufacturing processes used, dimensions, material, and quantity. The BOM incorporates all materials, components, and fasteners with estimates of raw material costs and purchased part costs. Assumptions on the sourcing of parts and in-house fabrication were based on industry experience, information in trade publications, and discussions with manufacturers. Interviews and plant visits were conducted with manufacturers to ensure accuracy on methodology and pricing.

Following the development of a detailed BOM, the major manufacturing processes were identified and developed for the spreadsheet model. Some of these processes are listed in Table 5.5.1.

Table 5.5.1 Major Manufacturing Processes

Fabrication	Finishing	Assembly/Joining	Quality Control
Fixturing Stamping/Pressing Brake Forming Cutting and Shearing Insulating Turret Punch Tube Forming Enameling	Washing Powder Coating De-burring Polishing Refrigerant Charging	Adhesive Bonding Spot Welding Seam Welding Packaging	Inspecting & Testing

Fabrication process cycle times for each part made in-house were estimated and entered into the BOM. Based on estimated assembly and fabrication time requirements, the labor content of each appliance could be estimated. For this analysis, $25.60 per hour was used as the average fully-burdened labor rate based on typical annual wages and benefits of industry employees.

Cycle requirements for fabrication steps were similarly aggregated by fabrication machine type while accounting for dedicated vs. non-dedicated machinery and/or change-over times (die swaps in a press, for example). Once the cost estimate for each teardown unit was finalized, a detailed summary was prepared for relevant components, subassemblies and processes. The BOM thus details all aspects of unit costs: material, labor, and overhead.

Design options used in units subject to teardown are noted in the summary sheet of each cost model and are cost-estimated individually. Thus, various implementations of design options can be accommodated, ranging from assemblies that are entirely purchased to units that are made entirely from raw materials. Hybrid assemblies, consisting of purchased parts and parts made on site are thus also accommodated.

5.5.3.4 Cost Model and Definitions

The cost model is based on production activities and divides factory costs into the following categories:

- Materials: Purchased parts (*i.e.*, motors, valves, *etc*.), raw materials, (*i.e.*, cold rolled steel, copper tube, *etc*.), and indirect materials that are used for processing and fabrication.
- Labor: Fabrication, assembly, indirect, and supervisor labor. Fabrication and assembly labor cost are burdened with benefits and supervisory costs.
- Overhead: Equipment, tooling, and building depreciation, as well as utilities, equipment and tooling maintenance, insurance, and property taxes.

Cost Definitions

Because there are many different accounting systems and methods to monitor costs, DOE defined the above terms as follows:

- Direct material: Purchased parts (out-sourced) plus manufactured parts (made in-house from raw materials).
- Indirect material: Material used during manufacturing (*e.g.*, welding rods, adhesives).
- Fabrication labor: Labor associated with in-house piece manufacturing.
- Assembly labor: Labor associated with final assembly.
- Supervisory labor: Labor associated with fabrication and assembly basis. Assigned on a span basis (x number of employees per supervisor) that depends on the industry.
- Indirect labor: Labor costs that scale with fabrication and assembly labor. These included the cost of technicians, manufacturing engineering support, stocking, *etc*. that are proportional to all other labor.
- Equipment depreciation: Money allocated to pay for initial equipment installation and replacement as the production equipment is amortized. All depreciation is assigned in a linear fashion and affected equipment life depends on the type of equipment.
- Tooling depreciation: Cost for initial tooling (including non-recurring engineering and debugging of the tools) and tooling replacement as it wears out or is rendered obsolete.
- Building depreciation: Money allocated to pay for the building space and the conveyors that feed and/or make up the assembly line.
- Utilities: Electricity, gas, telephones, etc.
- Maintenance: Annual money spent on maintaining tooling and equipment.
- Insurance: Appropriated as a function of unit cost.
- Property Tax: Appropriated as a function of unit cost.

5.5.3.5 Cost Model Assumptions

As discussed in the previous section, assumptions about manufacturer practices and cost structure played an important role in estimating the final product cost. In converting physical information about the product into cost information, DOE reconstructed manufacturing processes for each component using internal expertise and knowledge of the methods used by the industry. Site visits allowed DOE to confirm its cost model assumptions through direct observation of the manufacturing plant, as well as through manufacturer interviews, reviews of current Bureau of Labor Statistics data, etc.

5.5.4 Review of Previous Technical Support Documents and Models

DOE reviewed previous rulemaking TSDs to assess their applicability to the current standard setting process for residential clothes washers. These previous rulemaking TSDs served as a source for design options and energy consumption analysis, in addition to other sources.

5.5.5 Product Testing Methodology

Much of the analysis in this chapter relies on data from publicly available sources such as the CEC and ENERGY STAR databases. However, DOE also conducted its own limited performance testing according to the DOE test procedure for the following purposes:

- Verify performance trends that are apparent in the publicly available data;
- Develop a better understanding of the design options and product features currently available on the market;
- Develop a better understanding of the operational characteristics of residential clothes washers; and
- Evaluate possible active, standby, and off modes; the energy use in these modes; and the strategies manufacturers may take to reduce standby power.

As described further in section 5.6.2, DOE's testing generally confirmed the trends apparent in the publicly available data.

5.6 ANALYSIS AND RESULTS

5.6.1 AHAM Data

To support the DOE rulemaking, AHAM collected shipment and incremental manufacturing cost data from its member companies. At the time of the AHAM data collection, DOE was considering the same product classes defined in the current energy conservation standards (*i.e.*, top-loading standard, top-loading compact, top-loading semi-automatic, front-loading, and suds-saving.) For reasons of product availability and number of manufacturers, AHAM did not provide disaggregated data for top-loading compact, top-loading semi-automatic, and suds-saving clothes washers. Table 5.6.1 compiles unit shipment data for residential clothes washers from 2006–2008. AHAM began differentiating front-load and top-load shipments in 2006, so data broken down by method of loading prior to that year is unavailable. Note also that

AHAM did not specify whether the top-load category includes compact as well as standard-size units.

Table 5.6.1 AHAM Residential Clothes Washer Shipments Data Submittal

Year	Total Shipments	Front-Loading	Top-Loading
2006*	9,500,000	2,212,859	6,460,866
2007	8,825,000	2,883,828	5,941,197
2008	8,292,000	3,022,077	5,269,625

*Note: Front-load and top-load shipments do not sum to total domestic shipments in 2006 because the data baseline differs for both analyzed product types.

Table 5.6.2 reproduces AHAM's data submittal for the shipment-weighted average efficiency levels for top-loading and front-loading residential clothes washers. The data show the shipment-weighted MEF and WF for both product types. Again, AHAM did not indicate whether compact top-loading clothes washers were included in the top-load data; however, the small market share for these units would likely have a negligible effect on the weighted values.

Table 5.6.2 AHAM Residential Clothes Washer Shipment-Weighted Average Efficiency Data Submittal

	Front-Loading		Top-Loading	
Year	**Weighted MEF**	**Weighted WF**	**Weighted MEF**	**Weighted WF**
2006	1.99	5.12	1.24	11.38
2007	2.28	4.28	1.39	11.35
2008	2.26	4.23	1.44	10.88

AHAM provided market share efficiency data for top-loading (which specifically includes compact and standard-size) and front-loading residential clothes washers for 2006 to 2008, as shown in Table 5.6.3. All AHAM data are based on active mode efficiency levels. For some entries, market share data are provided combining multiple efficiency levels. In these cases, AHAM has combined the efficiency levels to maintain manufacturer confidentiality. The submitted values represent the market shares for clothes washers up to the listed efficiency levels. For example, the front-load efficiency level 3 market share for 2008 represents the front-loading clothes washers available with MEF from 2.2 to 2.4. This explains the large market share values reported at the max-tech efficiency levels.

Table 5.6.3 AHAM Residential Clothes Washer Market Share Efficiency Data Submittal

<table>
<tr><th rowspan="2">Efficiency Level MEF
(Front/Top-Load)</th><th colspan="3">Front-Loading (Standard)</th><th colspan="3">Top-Loading
(Compact and Standard)</th></tr>
<tr><th>2006</th><th>2007</th><th>2008</th><th>2006</th><th>2007</th><th>2008</th></tr>
<tr><td>Current Baseline (1.72/1.26)</td><td rowspan="2">10.7%</td><td rowspan="2">3.8%</td><td></td><td>93.7%</td><td rowspan="2">91.4%</td><td rowspan="2">87.2%</td></tr>
<tr><td>2011 Baseline (1.80/1.40)</td><td></td><td>0.0%</td></tr>
<tr><td>Level 1 (2.00/1.72)</td><td>32.9%</td><td>8.3%</td><td>4.3%</td><td>1.1%</td><td rowspan="2">1.2%</td><td rowspan="2">3.7%</td></tr>
<tr><td>Level 2 (2.20/1.80)</td><td>51.1%</td><td>19.7%</td><td>24.0%</td><td>0.0%</td></tr>
<tr><td>Level 3 (2.40/2.00)</td><td rowspan="2">5.3%</td><td>37.9%</td><td>48.9%</td><td>5.2%</td><td rowspan="2">7.3%</td><td rowspan="2">9.1%</td></tr>
<tr><td>Level 4 (2.89/2.25)</td><td>30.4%</td><td>22.8%</td><td>0.0%</td></tr>
</table>

AHAM provided incremental manufacturing cost data for both top-loading standard and front-loading standard clothes washers, as shown in Table 5.6.4 and Table 5.6.5. DOE converted these to 2010 dollars to make the AHAM data consistent with the downstream analysis, which was conducted in 2010 dollars. To perform the conversion, DOE scaled the costs using the producer price index (PPI) data from the Bureau of Labor and Statistics for NAICS 335224: Household laundry equipment manufacturing.

At the time DOE requested data from AHAM, the efficiency levels of interest were specified as those in the framework document for this rulemaking, which were based on MEF. Thus, the AHAM cost data are presented at the original values of MEF to which the aggregated data correspond. However, as DOE finalized the analysis, it determined that the efficiency levels would be based on IMEF, and also identified the need for an additional gap-fill efficiency level for front-loading clothes washers. Therefore, DOE's cost estimates and subsequent analyses are presented for the updated IMEF levels.

Table 5.6.4 AHAM Top-Loading Standard Clothes Washer Incremental Cost Data Submittal

Efficiency Level	MEF *(ft^3/kWh)*	Incremental Manufacturing Cost *($2009)*	Incremental Manufacturing Cost *($2010)*[1]
Baseline	1.26	$ -	$ -
EL 1	1.40	$3.10	$3.11
EL 2	1.72	$8.40	$8.44
EL 3	1.80	$13.00	$13.06
EL 4	2.00	$24.00	$24.11
EL 5	2.26	$59.20	$59.47

Table 5.6.5 AHAM Front-Loading Standard Clothes Washer Incremental Cost Data Submittal

Efficiency Level	MEF *(ft^3/kWh)*	Incremental Manufacturing Cost *($2009)*	Incremental Manufacturing Cost *($2010)*[1]
Baseline	1.72	$ -	$ -
EL 1	1.80	$ 2.00	$2.01
EL 2	2.00	$ 5.00	$5.02
EL 3	2.20	$ 16.00	$16.07
EL 4	2.40	$ 39.00	$39.18
EL 5	2.89	$ 72.00	$72.33

Figure 5.6.1 plots the incremental costs submitted by AHAM at the listed MEF efficiency levels for both the top-loading standard and front-loading residential clothes washer product classes. The lowest point on the graph indicates the baseline level and therefore has a cost increment of $0.

[1] DOE scaled AHAM's manufacturing costs to 2010 dollars based on PPI data available at http://www.bls.gov/ppi/.

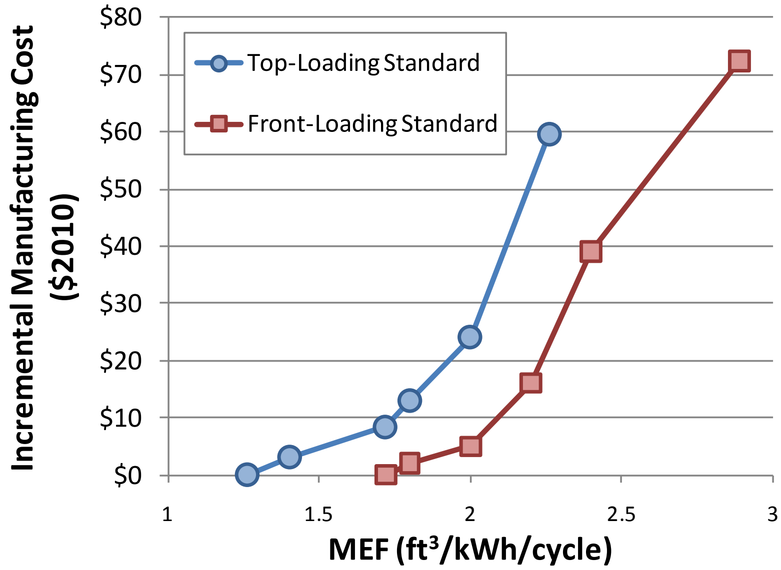

Figure 5.6.1 AHAM Residential Clothes Washer Incremental Cost Data Submittal

5.6.2 Product Testing Results

DOE tested a total of 23 clothes washer models in support of this rulemaking: eight top-loading standard units, two top-loading compact units, and 13 front-loading standard units. DOE also conducted teardowns on 23 clothes washer models: ten top-loading standard units, two top-loading compact units, and 11 front-loading standard units. DOE selected clothes washer models for testing and teardowns based on the proposed efficiency levels and the range of product efficiencies available on the market. Table 5.6.6 lists the major features of the top-loading standard clothes washers observed at each efficiency level. Table 5.6.7 and Table 5.6.8 list the major features of front-loading standard clothes washers observed at each efficiency level. As these tables indicate, manufacturers of front-loading standard clothes washers may choose different design option paths to achieve higher efficiency levels in their product lines. Table 5.6.9 lists the major features of the top-loading compact clothes washers in DOE's test sample.

Table 5.6.6 Top-Loading Standard Clothes Washer Test Unit Features

Feature	Top-Loading Clothes Washer Test Unit Efficiency Level						
	Baseline	**EL 1**	**EL 2**	**EL 3**	**EL 4**	**EL 5**	**EL 6**
Efficiency Level MEF *(ft^3/kWh)*	1.26	1.40	1.72	1.80	2.00	2.26	2.47
Efficiency Level WF *(gal/ ft^3)*	9.5	9.5	8.0	7.5	6.0	4.5	3.6
Rated Drum Capacity *(ft^3)*	3.2	3.5	3.5	3.9	4.0	4.1	4.5
Rated RMC *(%)*	51.9	53.6	48.8	37.9	36.6	36.6	34.8
Control Type	Electro-mechanical	Electro-mechanical	Electro-mechanical	Electronic	Electronic	Electronic	Electronic
Motor Type	PSC 1-Speed	PSC 2-Speed	PSC 2-Speed	Variable Speed PMM	Variable Speed PMM	Variable Speed PMM	Variable Speed PMM
Temperature Control	Thermal Switch	Thermistor	Thermistor	Thermistor	Thermistor	Thermistor	Thermistor
Fill Control	Electro-mechanical	Electro-mechanical	Electronic (auto)	Electronic (auto)	Electronic (auto)	Electronic (auto)	Electronic (auto)
Max RPM	640	640	640	950	1000	1000	1100
Wash Basket Material	Enameled Steel	Enameled Steel	Enameled Steel	Stainless Steel	Stainless Steel	Stainless Steel	Stainless Steel
Water Control Scheme	2-Way Solenoid	2-Way Solenoid	2-Way w/ Flowmeter	6-Way Solenoid	6-Way Solenoid	7-Way Solenoid	7-Way Solenoid
Fabric Softener Option	No	No	Yes	Yes	Yes	Yes	Yes
Spray Rinse	No	No	Yes	Yes	Yes	Yes	Yes
Agitator Type	Standard	Standard	Standard	Standard	Low-Profile	Low-Profile	Low-Profile
Internal Heater	No	No	No	No	No	Yes	No
Power Supply	Standard	Standard	Standard	Switch Mode	Switch Mode	Switch Mode	Switch Mode

Table 5.6.7 Front-Loading Standard Clothes Washer Test Unit Features

Feature	Front-Loading Clothes Washer Test Unit Efficiency Level				
	EL 1	**EL 2**	**EL 3**	**EL 3**	**EL 3**
EL MEF *(ft^3/kWh)*	1.80	2.0	2.2	2.2	2.2
EL WF *(gal/ ft^3)*	7.5	6.0	4.5	4.5	4.5
Rated Drum Capacity *(ft^3)*	3.0	3.3	3.2	3.5	3.5
Rated RMC *(%)*	41.4	41.6	40.4	34.4	39
Drive Type	Standard	Standard	Direct Drive	Standard	Standard
Temperature Sensors	0	1	1	1	2
Fill Control	Electro-mechanical	Electro-mechanical	Electro-mechanical	Electro-mechanical	Electronic
Max RPM	950	1050	1050	1100	1050
Water Control Scheme	3-Way Solenoid	2-Way Solenoid	4-Way Solenoid	2-Way Solenoid	3-Way w/ Flowmeter
Internal Heater	No	Yes	No	Yes	Yes
Recirculation	No	No	No	No	No
Power Supply	Switch Mode	Switch Mode	Transformerless	Switch Mode	Switch Mode

Table 5.6.8 Front-Loading Standard Clothes Washer Test Unit Features (continued)

Feature	Front-Loading Clothes Washer Test Unit Efficiency Level			
	EL 4	**EL 5**	**EL 5**	**EL 6**
EL MEF *(ft^3/kWh)*	2.4	2.6	2.6	2.89
EL WF *(gal/ ft^3)*	4.2	3.8	3.8	3.36
Rated Drum Capacity *(ft^3)*	3.6	3.8	3.9	3.6
Rated RMC *(%)*	38.7	36.3	36	33.1
Drive Type	Direct Drive	Standard	Direct Drive	Direct Drive
Temperature Sensors	1	2	1	1
Fill Control	Electro-mechanical	Electronic	Electro-mechanical	Electro-mechanical
Max RPM	1200	1300	1300	1200
Water Control Scheme	4-Way Solenoid	3-Way w/ Flowmeter	5-Way Solenoid	4-Way Solenoid
Internal Heater	Yes	Yes	Yes	Yes
Recirculation	No	no	Yes	No
Power Supply	Transformerless	Switch Mode	Transformerless	Transformerless

Table 5.6.9 Top-Loading Compact Clothes Washer Test Unit Features

Feature	Top-Loading Compact Clothes Washer Test Unit Efficiency Level		
	Baseline	Baseline	Baseline
Efficiency Level MEF *(ft^3/kWh)*	0.77	0.77	0.77
Efficiency Level WF *(gal/ ft^3)*	14.0	14.0	14.0
Rated Drum Capacity *(ft^3)*	1.5	1.5	1.3
Rated RMC *(%)*	58.4	N/A	N/A
Control Type	Electro-mechanical	Electro-mechanical	Electronic
Motor Type	PSC 2-Speed	PSC 1-Speed	N/A
Fill Control	Manual	Manual	Manual
Max RPM	640	400	690
Wash Basket Material	Enameled Steel	Stainless Steel	Stainless Steel
Water Control Scheme	2-Way Solenoid	2-way Solenoid	2-way Solenoid
Fabric Softener Option	No	No	No
Spray Rinse	No	N/A	N/A
Agitator Type	Standard	Low-Profile	Low-Profile
Internal Heater	No	No	No
Power Supply	Standard	Standard	Switch Mode

5.6.2.1 Active Mode Testing

Active mode clothes washer tests were first performed according to the current test procedure (appendix J1). The test procedure consists of running different load sizes of preconditioned test cloth in the clothes washer at various temperature settings. For all clothes washers, the minimum test load is 3 pounds of test cloth. Average and maximum load sizes are specified based on the clothes washer capacity. During the energy test cycles, the total kWh of electric energy consumed by the clothes washer is measured, in addition to the cold and hot water consumption. The measurements also include the "bone dry"[m] weight of the test load and the weight immediately after the completion of certain energy test cycles for the RMC calculation.

MEF is a function of capacity and per-cycle energy consumption, and WF is a function of capacity and per-cycle water consumption. DOE investigated the correlation between these variables and the efficiency metrics. These investigations helped DOE to determine the methods likely used by manufacturers to achieve higher efficiencies and the associated design options.

[m] "Bone dry" means a condition of a load of test clothes which has been dried in a dryer at maximum temperature for a minimum of 10 minutes, removed and weighed before cool down, and then dried again for 10-minute periods until the final weight change of the load is 1 percent or less.

Figure 5.6.2 shows the rated capacities and rated MEF values for the selected standard-size clothes washer test units. MEF is calculated as the capacity divided by energy use, so larger capacities should directly result in higher MEF ratings, all other variables held constant. The figure shows clear upward trends for both top-loading and front-loading clothes washers. DOE's informal tests confirmed these trends.

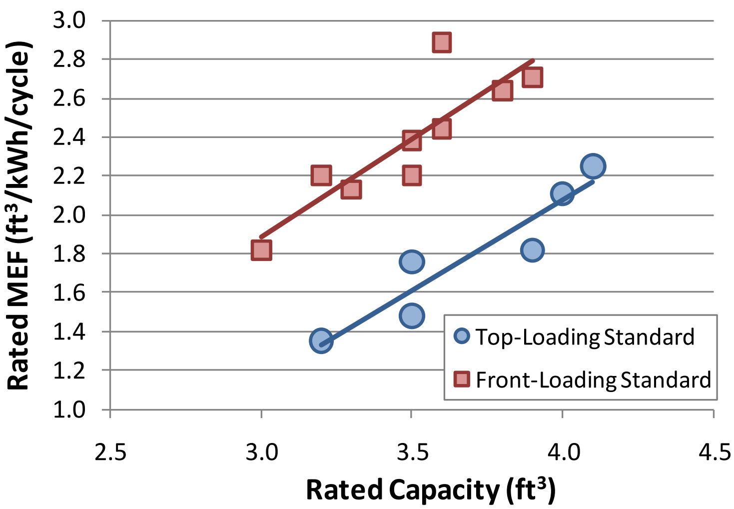

Figure 5.6.2 Rated MEF versus Rated Capacity

Figure 5.6.3 shows the rated per-cycle energy consumption and associated rated MEF for each test unit. Per-cycle energy consumption consists of machine electrical energy consumption and energy consumed to electrically heat the hot water used. Both top-loading and front-loading clothes washers show a downward trend between rated MEF and increasing per-cycle power consumption. DOE confirmed these trends through its testing.

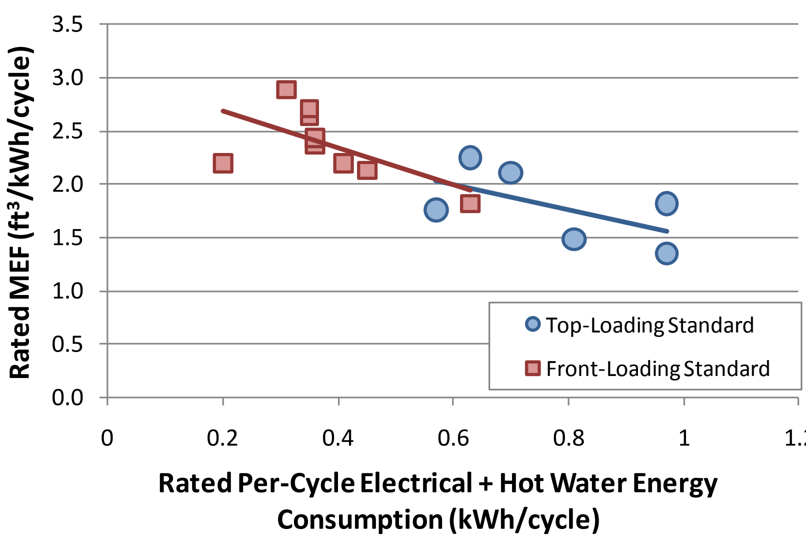

Figure 5.6.3 Rated MEF versus Rated Per-Cycle Energy Consumption

The remaining component of MEF is the energy needed to remove moisture from the test load. This is calculated using the RMC of the test load, and assuming a typical clothes dryer energy consumption weighted by a clothes dryer use factor. Lower RMC values mean more water is removed during the clothes washer spin cycle, leaving less to be removed in a dryer. Figure 5.6.4 shows that clothes washers with lower RMC values generally achieve higher MEF ratings. DOE's testing verified this general trend.

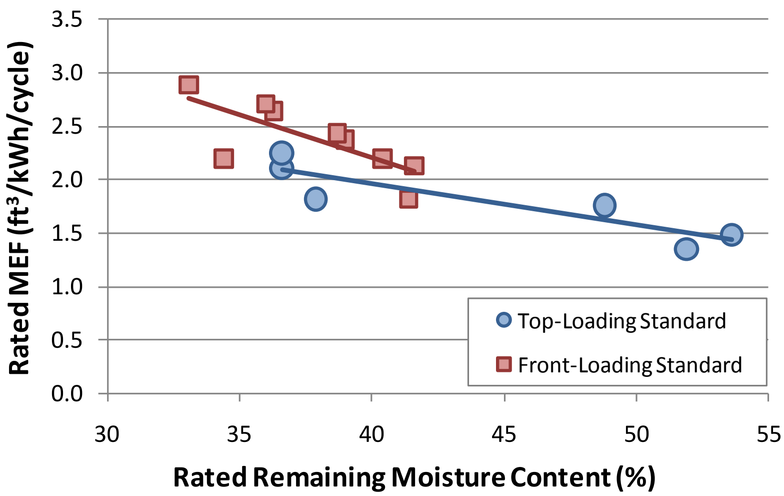

Figure 5.6.4 Rated MEF versus Rated RMC

Figure 5.6.5 shows a trend of lower WFs at higher capacities for both top and front-loading clothes washers. DOE confirmed this trend through its testing.

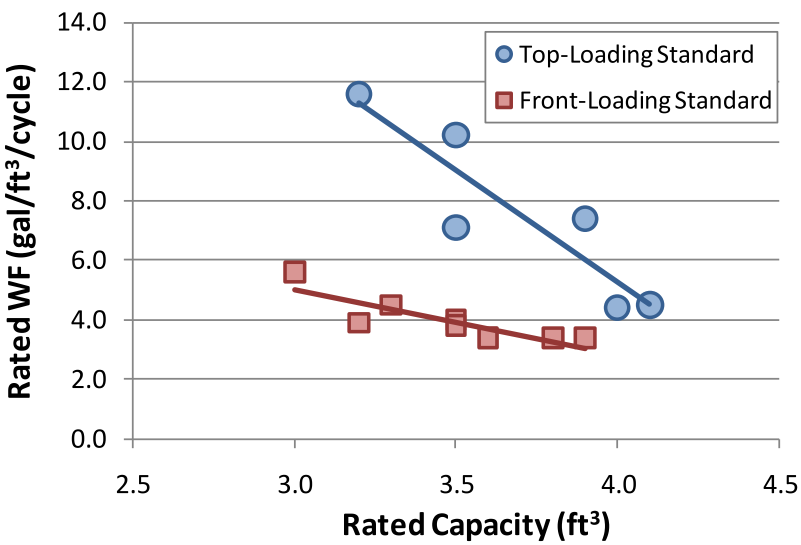

Figure 5.6.5 Rated WF versus Rated Capacity

During the reverse-engineering analysis, DOE determined that two front-load test units employ the same design and construction but are rated at different MEFs. DOE investigated the active mode test data for these two units to determine which parameters might result in the different MEF ratings. Figure 5.6.6 shows the cumulative water consumption for both test units during an individual hot wash/cold rinse energy test cycle. Unit #2 is the test unit with a higher MEF rating. The hot water consumption for unit #2 is less than the hot water consumption for unit #1, but cold water consumption is greater. This implies that unit #2 likely has a lower wash water temperature set-point. The test data from all energy test cycles show that unit #2 has lower hot water consumption in seven of the nine test cycles that use hot water, and on a weighted per-cycle basis, unit #2 uses 33 percent less hot water than unit #1. Hot water consumption directly impacts total energy use, which is used to calculate MEF, so unit #2 may be achieving a higher MEF by using lower wash temperatures.

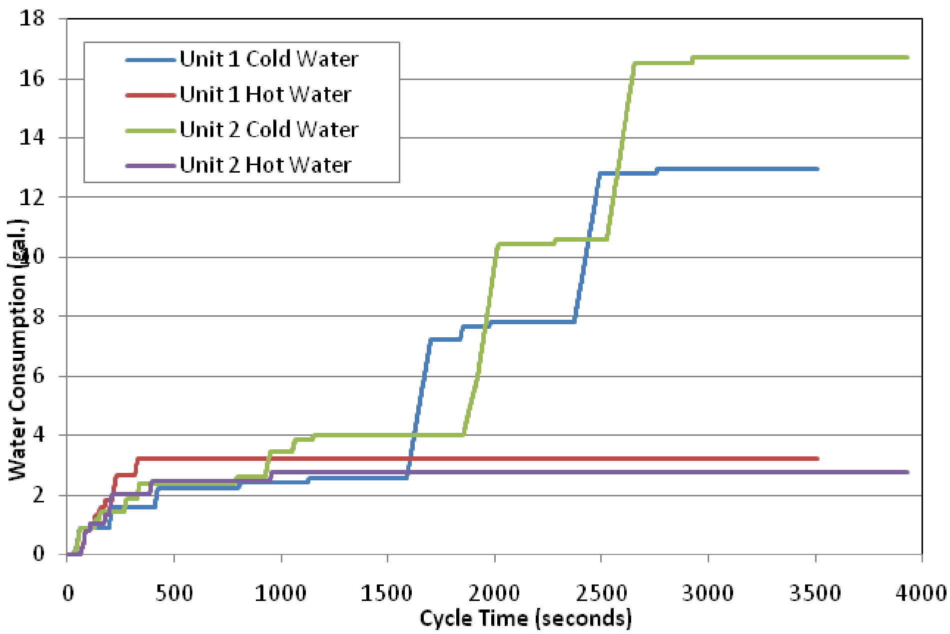

Figure 5.6.6 Cumulative Water Consumption versus Cycle Time

Also notable in Figure 5.6.6 is that unit #2 uses a longer wash cycle than unit #1. The two step increases in cold water consumption after 1500 seconds show the fills for cold water rinses. The flat period on the plot before the steps represents the wash cycle. For unit #2, the wash cycle lasts almost 2 minutes longer than the wash cycle in unit #1. Higher wash temperatures are generally associated with more effective cleaning, so unit #2 may compensate for a lower wash temperature by extending the length of the wash cycle.

Figure 5.6.7 shows the machine energy consumption for both test units over the same hot wash/cold rinse energy test cycle. Unit #2 consumes more electrical energy than unit #1 for the test cycle shown in the figure; on a weighted per-cycle basis, unit #2 uses about 5 percent more machine electrical energy than unit #1. Unit #2 is therefore likely achieving a higher MEF through means other than reduced machine electrical energy use.

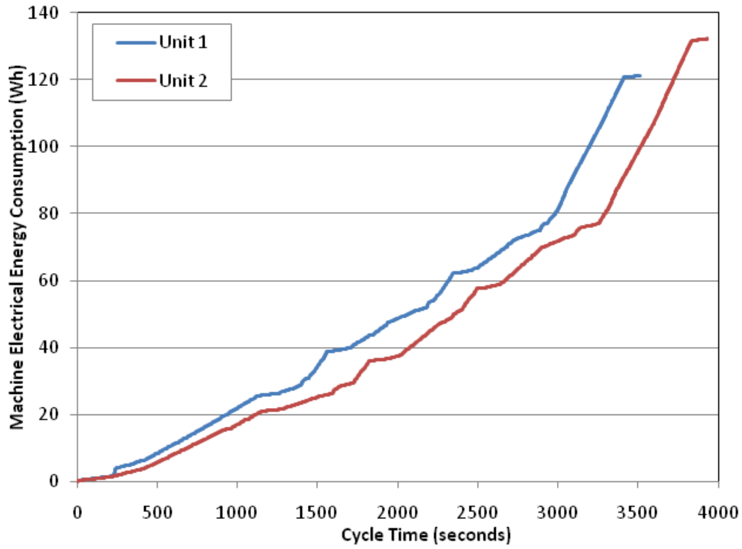

Figure 5.6.7 Machine Cumulative Electrical Energy Consumption versus Cycle Time

The energy required to remove moisture from the test load is much lower for unit #2 than for unit #1—the result of a lower RMC value. Both units have the same construction and maximum spin speed, but the spin cycle duration for unit #2 is longer than for unit #1. The steeper sections of the plots at the end of the test cycle shown in Figure 5.6.7 represent the spin cycle. For this energy test cycle, the machine electrical energy consumption is greatest during the spin cycle, resulting in a steeper slope on the plot. Figure 5.6.7 shows that for this energy test cycle, unit #2 has a spin cycle lasting about 2 minutes longer than that of unit #1. This also likely contributes to the greater machine electrical energy consumption for unit #2.

DOE's test data show that unit #2 likely achieves a higher MEF than unit #1 by using less hot water and longer spin cycles to reach a lower RMC, despite the associated increase in machine electrical power consumption. While these changes do not have any associated design changes or incremental cost, they do impact consumer utility. The cycle times are longer for unit #2 due to longer wash and spin cycles. Additionally, consumers may not experience the same cleaning performance from these two clothes washers, due to differences in wash water temperature and overall water consumption.

To summarize key findings from the active mode testing of a sampling of residential clothes washers, DOE observed the following:

- DOE's testing generally confirmed the trends apparent in the publicly available data.
- Similar general trends are observed for top-loading and front-loading clothes washers.
- Manufacturers generally utilize a combination of improvements to multiple contributing parameters to achieve higher MEF and/or lower WF.
- Increases to MEF can be achieved with no corresponding mechanical design changes by adjusting control settings such as wash water temperature, wash cycle duration, and spin cycle duration; however, these changes may impact consumer utility.

5.6.2.2 **Standby and Off Mode Testing**

DOE measured standby and off mode power for all 15 clothes washers selected in the test sample, using the methodology provided in IEC Standard 62301 First Edition. The current version of this standard is IEC Standard 62301 Second Edition, which contains revisions affecting the definitions and measurement methodology of standby and off-mode power. However, DOE believes that the methodology of the Second Edition would produce nearly identical standby power consumption measurements. Data obtained from standby and off mode testing are presented in section 5.4.4.

5.6.3 Product Teardowns

As part of its reverse-engineering process, DOE conducted teardowns of clothes washers to identify design features and corresponding manufacturing costs that are associated with successively higher efficiency levels. The clothes washer teardown analysis performed for this analysis included 17 teardown units total from the top-loading standard, front-loading standard, and top-loading compact product classes.

DOE noted that all of the clothes washers it examined were constructed with an outer sheet metal assembly consisting of panels or an outer wrapper that had been formed by stamping. This assembly houses the cylindrical drum, drive motors, control systems, and the associated tubing and wiring. Details of these components and sub-assemblies are as follows.

5.6.3.1 **Baseline Construction: Top-Loading Standard Clothes Washer**

The baseline top-loading standard clothes washer is equipped with electromechanical controls that allow the user to select specific cycle settings. These include switches for wash temperature and load size. Temperature is controlled using a thermal cutout on the water inlet assembly, which consists of two solenoid valves. The baseline unit offers three wash temperature selections. The load size selector switch determines the fill level for a wash cycle, which is controlled by an electromechanical pressure switch. Three load size selections are available on the baseline unit.

The motor is a ½-horsepower permanent split capacitor (PSC) motor which drives the drum and the agitator. On some baseline models, this motor also drives the drain pump by reversing direction, while other manufacturers opt to include a dedicated drain pump instead. The baseline wash basket consists of an enameled steel cylinder with a circular plate attached to the bottom to form a drum. From the center of the bottom plate a smaller cylinder rises to guide the drive shaft into the impeller and to center the wash basket inside the tub. Snapped onto the top rim of the drum is a plastic balance ring, which is partially filled with a saline solution. Covering the balance ring is a plastic cover, often referred to as the tub cover, which typically includes a housing for bleach dispensing.

The outer wrapper of the baseline unit consists of stamped metal panels which may be made of pre-painted steel or coated post-fabrication with powder-coat paint. The top panel houses the lid, which is a smaller stamped piece of sheet metal on hinges. One of these hinges triggers a limit switch that cuts power to the motor when the lid is opened. The top panel and lid may be enameled on higher-end units.

Based upon product teardowns, DOE developed the following baseline production and materials cost distributions for a top-loading clothes washer. Table 5.6.10 and Figure 5.6.8 show the baseline production cost distributions; and Table 5.6.11 and Figure 5.6.9 show the baseline materials cost distribution. Depending on the manufacturer and the production volume, the depreciation costs may vary from those shown in the figures, which assume a “green-field” site.

Table 5.6.10 Baseline Top-Load Standard Clothes Washer Production Cost Distribution

Cost Category	Total Cost *($2010)*
Raw Materials	$98.92
Purchased Parts	$90.21
Assy Labor Cost	$9.88
Fab Labor Cost	$5.71
Indirect Labor Cost	$5.40
Supervision Cost	$0.81
Tooling Dep. Cost	$16.28
Indirect Process Costs	$2.77
Equipment Dep. Cost	$2.27
Building Dep. Cost	$1.50
Maintenance	$5.05
Utility Cost	$4.00
Property Tax	$2.87
Insurance	$1.97
Total	**$ 247.66**

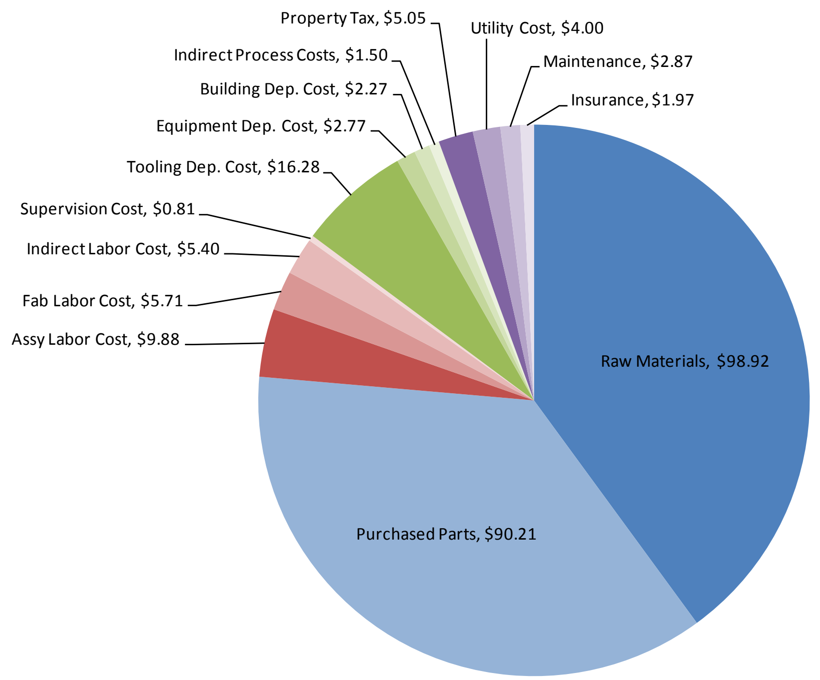

Figure 5.6.8 Baseline Top-Load Standard Clothes Washer Production Cost Distribution

Table 5.6.11 Baseline Top-Load Standard Clothes Washer Materials Cost Distribution

Sub-Assembly	Total Materials Cost *($2010)*
Motor/Pump/Capacitor	$37.61
Controls	$31.85
Outer Wrapper	$24.32
Gearbox/Transmission	$26.53
Tub/Drum	$25.31
Suspension	$17.62
Packaging	$7.84
Wire Harness	$7.05
Water Temp Management	$2.83
Final Assy	$4.00
Door	$4.17
Total	**$ 189.13**

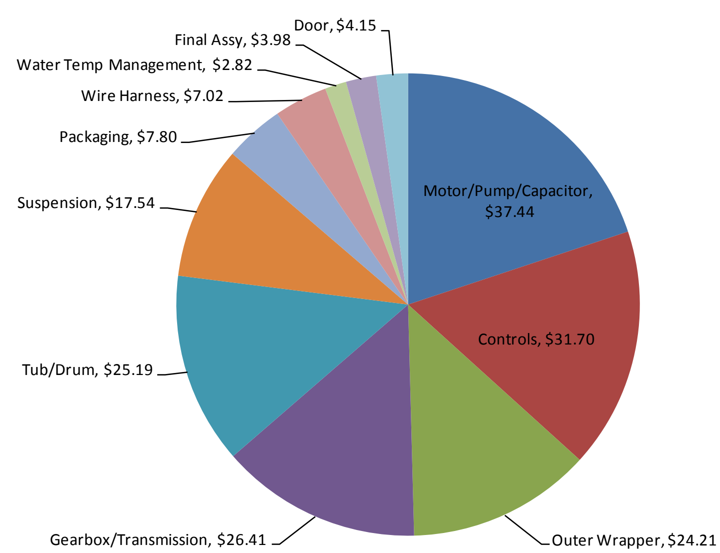

Figure 5.6.9 Baseline Top-Load Standard Clothes Washer Materials Cost Distribution

5.6.3.2 **Baseline Construction: Front-Loading Standard Clothes Washer**

DOE is unaware of any front-loading residential clothes washers currently available on the market that are at or above the baseline efficiency level but do not meet EL 1. For this reason, DOE established the baseline construction for a front-loading clothes washer at EL 1.

The baseline front-loading clothes washer is equipped with basic electronic controls that allow the user to select specific cycle settings. These include switches to select a wash cycle and wash temperature. Light-emitting diodes (LEDs) confirm the user selections, but there is no numerical display. Four wash temperatures can be selected, and the temperature is controlled using two water inlet solenoid valves combined with a third solenoid to control the flow of the mixed water. From the inlet solenoid assembly, the water flows through a detergent dispenser tray before entering the wash basket. There are no temperature sensors in the baseline unit, and the water fill level for a wash cycle is automatically controlled using an electromechanical pressure switch.

The internal tub/drum assembly of the baseline front-loading clothes washer is supported by four suspension legs attached to a plastic base plate. Two springs attached to the upper sides of the outer wrapper also support the tub/drum assembly from above. The tub/drum assembly consists of an internal rotating basket and a plastic wash tub. The basket is made of a stainless steel cylinder with an attached front ring and back plate. Attached to the back plate is a cast aluminum connector piece that secures the drive shaft. Molded into the back half of the tub is a cast iron hub that houses two bearings, which guide the drive shaft. A variable speed motor powers the drive shaft using a drive belt and drive wheel. The motor is attached to the plastic base plate. Also attached to the base plate is a drain pump.

The outer wrapper of the baseline unit consists of individual side, back, and top panels made of pre-painted stamped cold-rolled steel (PCRS) that are clinched together. The front panel, which is a smaller stamped piece of PCRS, houses the door assembly. A large piece of tempered glass with a plastic frame and handle make up the door assembly, which is attached to the front panel by a hinge. A door latch inside the front panel locks the door shut during the wash cycle. Attached to the front of the internal wash tub is a door seal gasket. This is a flexible ring that extends forward from the wash tub to create a water-tight seal when the door is shut.

Based on product teardowns, DOE production and materials cost distributions for the baseline front-loading clothes washer. Table 5.6.12 and Figure 5.6.10 show the total cost distribution, and Table 5.6.13 and Figure 5.6.11 show the materials cost distribution. Depending on the manufacturer and the production volume, the depreciation costs may vary from those shown in the figures, which assume a green-field site.

Table 5.6.12 Baseline Front-Load Clothes Washer Production Cost Distribution

Cost Category	Total Cost *($2010)*
Purchased Parts	$234.83
Raw Materials	$155.79
Assy Labor Cost	$27.73
Indirect Labor Cost	$14.42
Fab Labor Cost	$13.81
Supervision Cost	$2.16
Tooling Dep. Cost	$29.96
Indirect Process Costs	$10.40
Equipment Dep. Cost	$5.83
Building Dep. Cost	$1.85
Utility Costs	$8.42
Property Tax	$4.58
Maintenance Costs	$4.23
Insurance Costs	$4.11
Total	**$515.75**

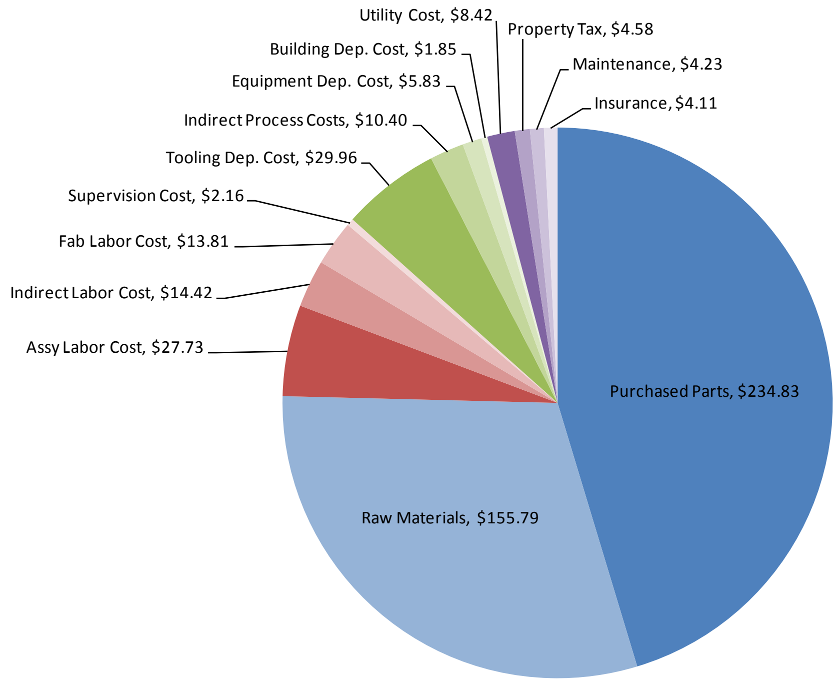

Figure 5.6.10 Baseline Front-Load Standard Clothes Washer Production Cost Distribution

Table 5.6.13 Baseline Front-Load Clothes Washer Materials Cost Distribution

Sub-Assembly	Total Materials Cost *($2010)*
Tub/Drum	$107.49
Controls	$106.12
Motor/Pump/Capacitor	$58.94
Outer Wrapper	$46.85
Door	$16.88
Packaging	$14.91
Water Temp Management	$14.17
Wire Harness	$14.07
Final Assy	$6.39
Suspension	$4.80
Total	**$390.62**

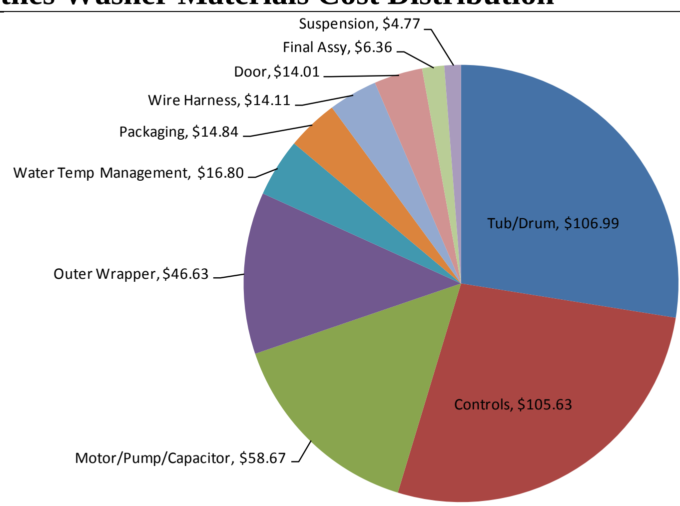

Figure 5.6.11 Baseline Top-Load Standard Clothes Washer Materials Cost Distribution

5.6.3.3 **Baseline Construction: Top-Loading Compact Clothes Washer**

The baseline top-loading compact clothes washer is equipped with electromechanical controls that allow the user to select specific cycle settings. These include switches for wash temperature and load size. Temperature is controlled using a thermal cutout on the water inlet assembly, which consists of two solenoid valves. The baseline unit offers four wash temperature selections. The load size selector switch determines the fill level for a wash cycle, which is controlled by an electromechanical pressure switch. Three load size selections are available on the baseline unit.

The motor is a ½-horsepower permanent split capacitor (PSC) two-speed motor which drives the drum and the agitator. The baseline wash basket consists of an enameled steel cylinder with a circular plate attached to the bottom to form a drum. From the center of the bottom plate a smaller cylinder rises to guide the drive shaft into the impeller and to center the wash basket inside the tub. Snapped onto the top rim of the drum is a plastic cover, often referred to as the tub cover.

The outer wrapper of the baseline unit consists of stamped metal panels which may be made of pre-painted steel or coated post-fabrication with powder-coat paint. The top panel houses the lid, which is a smaller stamped piece of sheet metal on hinges. One of these hinges triggers a limit switch that cuts power to the motor when the lid is opened.

Due to the limited number of manufacturers of top-loading compact clothes washers, and the need to maintain manufacturer confidentiality, DOE is unable to show the baseline production and materials cost distributions for a baseline top-loading compact clothes washer. DOE observed, however, that the total cost of production for a compact top-loading clothes washer roughly equals the total cost of production for a standard-size top-loading clothes washer. Any reductions in materials cost due to the smaller size are mostly offset by higher costs for specialized parts, which are produced in much lower quantities for the compact product class.

5.6.3.4 **Baseline Construction: Front-Loading Compact Clothes Washer**

As described previously, currently no front-loading compact clothes washers exist in the United States market. Therefore, DOE was unable to perform a teardown analysis. Based on the observation for the top-loading compact class, DOE estimates that the baseline production cost for a compact front-loading clothes washer would roughly equal the total cost of production for a standard-size front-loading clothes washer.

5.6.3.5 **Construction at Higher Efficiency Levels**

Based on the design options retained from the screening analysis (see chapter 4 of this TSD), the reverse-engineering analyses, and discussions with manufacturers, summarized in section 5.6.5, DOE developed manufacturing costs associated with various design features necessary to achieve higher efficiencies.

The following are the design changes DOE believes would be necessary to meet each active mode efficiency level, which were subsequently modeled to obtain incremental manufacturing cost estimates. Note that the efficiency levels listed here must be adjusted to obtain the integrated efficiency levels, which factor in standby power and other changes to the test procedure.

Top-Loading Standard Clothes Washers

MEF Efficiency Level 1

Based on characteristics of units selected for teardown and based on discussions with manufacturers, DOE research suggests that EL 1 is typically achieved in top-loading clothes washers through four changes:

1. Improved Temperature Control

Through its observations and discussions with manufacturers, DOE believes that in moving from the baseline level to EL 1, manufacturers would likely replace a thermal cutout with a thermistor in the inlet water solenoid assembly. A thermistor would allow for multiple temperature set-points, which could result in improved water temperature control. Eliminating excess hot water use would improve MEF.

2. Improved Fill Level Control

Improved fill level control reduces wash water consumption. Baseline and EL 1 clothes washers would both likely use an electromechanical pressure sensor to control the fill level. However, DOE expects manufacturers to use a pressure sensor at EL 1 with multiple fill level set-points. Multiple fill level options can reduce water consumption, if used properly.

3. Increased Capacity

Capacity is used directly in the calculations for MEF and WF, and an increase in capacity results in an improvement in both metrics. At EL 1, manufacturers would likely increase capacity from a baseline 3.2 ft^3 to around 3.5 ft^3.

4. Two-Speed Motor

DOE believes that manufacturers would likely switch from a single-speed motor at the baseline efficiency level to a two-speed motor at EL 1. The motors both have the same maximum speed, but the two-speed motor would allow for more flexibility throughout the cycle. Manufacturers may choose to use the lower spin speed during the wash cycle, consuming less electrical energy, but likely requiring longer spin duration.

MEF Efficiency Level 2

Through research and discussions with manufacturers, DOE believes that the EL 2 clothes washer would still use a two-speed motor, and would likely have the same capacity as an

EL 1 clothes washer. To reach EL 2, manufacturers would likely improve on the other design options used for EL 1, and would incorporate certain additional features:

1. Improved Temperature Control

To achieve EL 1, the temperature control scheme likely features a thermistor and four wash temperature set-points. A thermistor would also likely be used to reach EL 2, but with five temperature set-points instead of four. More temperature set-points would help to reduce excess hot water, improving efficiency.

2. Improved Fill Level Control

DOE believes manufacturers would likely offer automatic fill controls at EL 2. This includes switching to an electronic pressure transducer with embedded control logic, and adding a flowmeter. The electronic pressure sensor and control logic would allow the clothes washer to determine the load size based on the measured volume of water introduced to the clothes container and the transient water pressure measured at the bottom of the tub, which is affected by the load size. These controls would reduce excess water consumption by filling the wash basket with the minimum volume of water needed to soak the load. All other control components on an EL 2 clothes washer would likely remain electromechanical, as expected for the baseline and EL 1 efficiency level clothes washers.

3. Fabric Softener Option

The EL 2 clothes washer would likely feature a fabric softener option. Fabric softener requires a certain volume of water to dilute it and ensure it will not damage clothing. Without a fabric softener option, manufacturers must design the wash cycles to include this extra amount of water to maintain fabric quality. The fabric softener option allows the clothes washer to consume the added amount of water only when the consumer selects that option. Since the energy test cycle would not be tested with the fabric softener option activated, lower water usage would be achieved for the purposes of measuring MEF and WF.

4. Spray Rinse

Manufacturers would likely employ a spray rinse at EL 2. Spray rinse significantly decreases the volume of water used during the rinse cycle. The clothes washers at the baseline level and EL 1 typically use a deep rinse, during which the tub is filled with water to a level in which the clothes are submerged, agitated, and then drained to remove soap suds. A spray rinse uses high-pressure jets of water to rinse the load while the basket is spinning, without requiring the clothes to be immersed.

MEF Efficiency Level 3

DOE research suggests that manufacturers would likely significantly change the design of a top-loading standard-size clothes washer to reach EL 3. A clothes washer at EL 3 is likely to employ some of the same features as one at EL 2, such as load sensing, spray rinse, and a fabric softener option. The significant design changes are:

1. Electronic Controls

Manufacturers would likely use all electronic controls in an EL 3 clothes washer. This includes a control board for the user interface, with a numerical display, and a main control board.

2. Direct Drive Motor

A direct drive motor would likely replace the standard two-speed PSC motor to reach EL 3. A direct drive motor does not require a transmission or a drive system to power the drive shaft. The drive shaft is directly attached to the rotor, which allows the motor to fit below the wash tub. This design change is accompanied by a significant structural change: the tub and basket assembly is now always supported from the top of the outer wrapper assembly by four suspension rods, rather than from the bottom as in some lower efficiency washers. This motor implementation also requires a separate drain pump.

3. Improved Fill Level Control

Manufacturers would likely improve the automatic fill control at EL3. One implementation that DOE has observed used a floating wash basket design which allows the washer to detect when the clothes inside it have been saturated with water. The control scheme would be programmed to stop the inlet water flow after the basket begins to float.

4. Improved Water Flow Control

At EL 3, manufacturers would likely use a combination of electronically controlled thermistors and solenoid valves to achieve more precise water flow control. The thermistors sense the internal water temperatures, and the control system actively adjusts the solenoid valves to maintain the desired internal wash temperature.

5. Stainless Steel Wash Basket

Manufacturers would likely switch construction of the wash basket from enameled cold rolled steel to stainless steel at EL 3. According to interviews with manufacturers, stainless steel wash baskets are able to tolerate higher spin speeds, which yield lower RMC values. From baseline to EL 2, spin speeds would likely be around 640 RPM. Switching to a stainless steel wash basket, in addition to an improved motor and a lid-locking assembly, would allow clothes washers to reach spin speeds of up to 1100 RPM.

6. Increased Capacity

The direct-drive motor mentioned above eliminates the need for a gearbox, clutch, counterweight, and other accessories underneath the tub. Due to its low profile, it gives manufacturers the option to make the tubs and wash baskets deeper and hence more voluminous. At EL 3, manufacturers would likely increase capacity from 3.5 ft^3 to around 3.8 ft^3.

7. Water Recirculation

DOE believes that manufacturers would likely use a recirculation pump at EL 3 to decrease water consumption. Recirculation pumps take water from the bottom of the wash tub back to the top to help ensure effective washing throughout the wash basket.

MEF Efficiency Level 4

Based on torn-down units and discussions with manufacturers, DOE believes that to reach EL 4, manufacturers would likely employ similar features as those seen at EL 3. The EL 4 structural design is also likely largely the same design used at EL 3. DOE expects only two major design changes moving from EL 3 to EL 4:

1. Low-Profile Agitator Design

DOE believes manufacturers would likely move to a low-profile agitator design at EL 4. The low-profile agitator design consists of a rotating flat plate at the bottom of the wash basket, compared to the standard agitator, which is a finned cylinder that rises axially into the wash basket. The low-profile agitator results in more volume for clothes inside the wash basket, and therefore leads to a higher capacity rating which improves MEF and WF.

2. Multiple Spin Speeds

DOE expects manufacturers to offer multiple spin speed selections on top-loading clothes washers at EL 4. For EL 3, spin speed is determined only by wash cycle selection. The clothes washer at EL 4 would likely still default to a spin speed based on wash cycle selection, but would allow the user to change the setting.

MEF Efficiency Level 5

DOE believes that the design features used at EL 4 would also apply to EL 5. Manufacturers would likely make one additional change to the EL 4 design:

1. Increased Capacity

DOE believes that clothes washers at EL 5 would likely have a slightly larger capacity than those at EL 4. Manufacturers would likely produce top-loading clothes washers with capacities greater than 4 ft^3 to meet EL 5.

MEF Efficiency Level 6

Manufacturers would likely make two changes to the EL 5 design:

1. Increased Capacity

DOE believes that clothes washers at EL 6 would likely have a slightly larger capacity than those at EL 5. Manufacturers would likely produce top-loading clothes washers with capacities as high as 4.5 ft^3 to meet EL 6.

2. Increased Spin Speed

DOE believes that clothes washers at EL 6 would likely have slightly higher spin speeds than those at EL 5, resulting in lower RMC values.

Front-Loading Standard Clothes Washers

For front-loading clothes washers, DOE observed that manufacturers employ unique designs and different technology options to reach higher efficiencies. No single manufacturer produces units at all efficiency levels, so it is difficult to associate incremental design changes to specific active mode efficiency levels. The following sections describe the general technology options DOE observed at each efficiency level. DOE does not expect that a manufacturer would use all technology options listed to reach a certain efficiency level, but would choose some combination of the observed features.

MEF Efficiency Level 1

As described previously in this section, DOE is unaware of any front-loading clothes washers available on the market that meet or exceed the baseline efficiency, but do not meet EL 1. Therefore, the EL 1 unit has the same construction and design features as the previously described baseline front-loading clothes washer.

MEF Efficiency Level 2

Through teardowns and discussion with manufacturers, DOE believes that manufacturers would likely rely on some or all of the following design options to reach EL 2:

1. Increased Capacity

Manufacturers would likely use a slight increase in capacity to raise efficiency from EL 1 to EL 2. DOE observed roughly a 10-percent increase in capacity. The increase in capacity also requires a larger frame and outer wrapper.

2. Internal Water Heating

A front-loading clothes washer at EL 1 would most likely not include an internal heater. At EL 2, manufacturers would likely add a rod heater to the bottom of the tub assembly. DOE expects internal water heating to be more efficient than external water heating for achieving the extra-hot temperature settings offered on many front-loading models at EL 2.

3. Improved Temperature Control

DOE believes that manufacturers would likely add a thermistor to the EL 2 front-loading clothes washer to improve temperature control. The EL 1 unit uses only two solenoid valves to control the flow of hot and cold water to regulate temperature. A thermistor provides feedback to adjust the solenoid valves as needed, and to control operation of the internal water heater.

4. Increased Maximum Spin Speed

Manufacturers would likely increase the maximum spin speed for a front-loading clothes washer at EL 2. DOE believes the spin speed would be increased by roughly 100 RPM at EL 2. This results in a lower RMC and higher MEF. To achieve higher spin speeds, the clothes washer at EL 2 also requires an improved motor.

MEF Efficiency Level 3

DOE observed through teardowns and learned from discussions with manufacturers that the following design options would likely be used to move from EL 2 to EL 3:

1. Increased Capacity

DOE believes that manufacturers would likely increase capacity somewhat further to raise efficiency from EL 2 to EL 3.

2. Improved Fill Level Control

As seen for top-loading clothes washers, one method used to improve water flow control is to incorporate an electronic pressure sensor and a flowmeter. All of the front-loading clothes washers DOE analyzed incorporate automatic fill control, but not all use electronic pressure sensors. DOE believes that some manufacturers would employ an electronic pressure sensor and a flowmeter at EL 3 to improve water fill level control.

3. Improved Control Scheme

DOE believes that some manufacturers would likely adjust control parameters to improve efficiency at EL 3. Through its active mode testing, DOE observed that longer spin cycles and lower wash temperature set-points correspond to lower RMC values and less hot water consumption, respectively. Neither of these changes is associated with any physical design change to the clothes washer, but they may impact consumer utility, as described in section 5.6.2.

4. Direct Drive Motor

Certain manufacturers would likely use a direct drive motor on their front-loading clothes washers at EL 3. This would replace the standard variable-speed motor, drive belt, and drive wheel used on the clothes washers at lower efficiency levels.

5. Improved Internal Water Heating

DOE observed that some manufacturers use multiple heating rods at EL3. DOE believes that using multiple heating rods may enable more precise hot water temperature control.

MEF Efficiency Level 4

To increase efficiency from EL 3 to EL 4, manufacturers would likely use three design options, which are an extension of the options used to reach the previous efficiency levels:

1. Increased Capacity

Manufacturers would likely incorporate another slight increase in capacity to improve MEF and WF from EL 3 to EL 4.

2. Improved Control Scheme

DOE believes that some manufacturers would rely on longer spin cycles and lower wash temperature set-points to reach EL 4.

3. Increased Maximum Spin Speed

Manufacturers would likely increase the maximum spin speed for a front-loading clothes washer at EL 4. DOE believes the spin speed would be roughly 100 RPM higher than the spin speed at EL 2 and EL 3. To achieve higher spin speeds, the EL 4 clothes washer requires an improved motor.

MEF Efficiency Level 5

DOE believes manufacturers would likely use three design options to increase efficiency from EL 4 to EL 5:

1. Increased Capacity

DOE observed front-loading clothes washer capacities at EL 5 approaching 4 ft^3 as compared to 3 ft^3 at the baseline. For the units DOE tore down at this efficiency level, the capacity increase does not require a different frame or outer wrapper assembly, which limits the associated incremental cost. However, other manufacturers may require a larger frame and outer wrapper to reach such large capacities.

2. Increased Maximum Spin Speed

DOE expects that manufacturers would likely increase the maximum published spin speed to around 1300 RPM at EL 5. During its active mode testing, DOE observed that the EL 5 test units use a shorter spin cycle than the lower efficiency units from the same manufacturers. Despite the shorter spin cycle, the EL 5 units have lower RMC ratings, likely because of the increased spin speeds.

3. Water Recirculation

DOE believes that certain manufacturers would likely use a recirculation pump at EL 5 to decrease water consumption.

MEF Efficiency Level 6

DOE believes that manufacturers would likely use two design options to increase efficiency from EL 5 to EL 6:

1. Increased Capacity

DOE believes capacities at EL 6 would exceed 4 ft^3.

2. Longer Spin Cycle

DOE expects that EL 6 units would also have a maximum spin speed of 1300 RPM and up. The EL 6 unit would likely have longer spin cycle duration than the EL 5 unit. During its active mode testing, DOE observed that the EL 6 test units have lower RMC values than EL 5 units.

Through its teardown analysis and active mode testing, DOE believes that manufacturers may alternatively achieve EL 6 from EL 4 or EL 5 via an improved control scheme alone. The EL 6 unit likely could employ the same design features as an EL 4 or EL 5 unit, but would use a longer spin cycle duration, and a lower wash temperature set-point. DOE observed the longest spin cycles and lowest wash water temperatures in the EL 6 unit in its test sample, and noted that these were the only functional changes from lower efficiency levels. However, DOE believes that manufacturers may choose to use a combination of increased capacity and higher spin speeds, as seen at EL 5, in conjunction with less dramatic changes to the control scheme, to reach EL 6. From information gained through discussions with manufacturers, DOE believes that certain manufacturers would resist changing the control scheme so drastically because of the potential effects on wash performance and consumer utility.

Consumer utility at the higher efficiency levels may also be affected by overall cycle time. DOE investigated the relationship between cycle time and efficiency level, using data collected during its testing, supplemented with additional cycle times published by manufacturers in product literature. Figure 5.20 and Figure 5.6.13 present the average times for the normal cycle for both top-loading and front-loading clothes washers. The data are shown in terms of MEF and WF in order to provide a consistent basis of comparison between published information and DOE's results. It can be observed generally that front-loading clothes washers require longer cycle times than top-loading models, and that the top-loading cycle times are relatively constant regardless of the efficiency level. For front-loading clothes washers, however, it can be seen that cycle time increases at the highest efficiency levels, particularly as water consumption is reduced, as indicated by WFs of 4 gal/ft^3 or below (*i.e.*, front-loading MEF Efficiency Level 5 or higher).

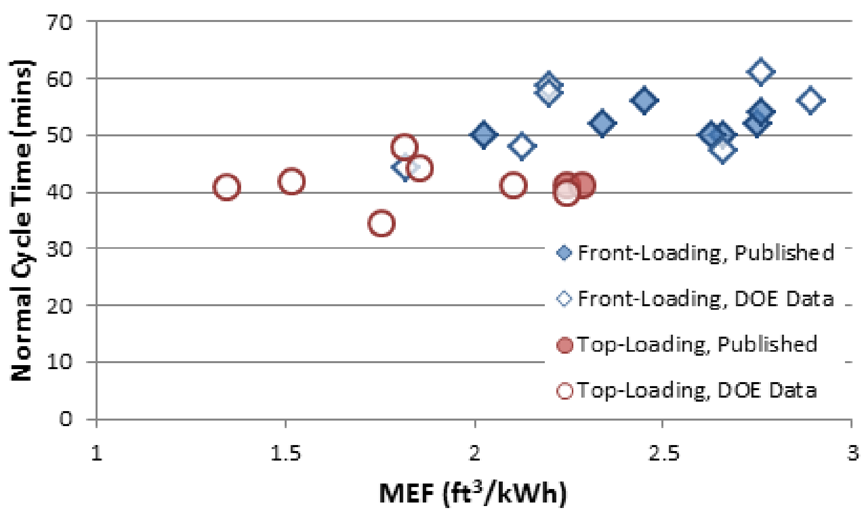

Figure 5.6.12 Cycle Time as a Function of MEF

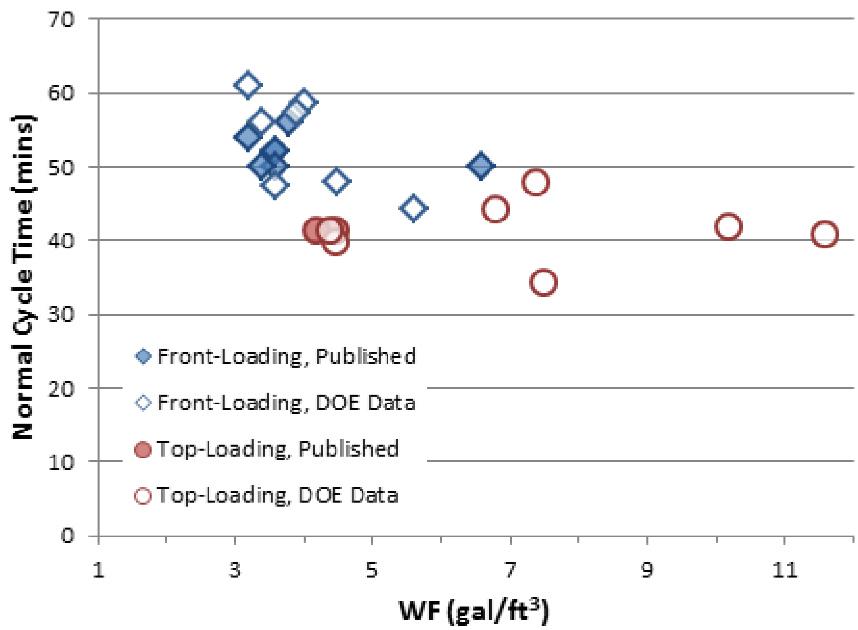

Figure 5.6.13 Cycle Time as a Function of WF

Top-Loading Compact Clothes Washers

MEF Efficiency Level 1

Based on energy and water consumption modeling using the design option approach and discussions with manufacturers, DOE believes that EL 1 could be achieved with the following changes:

1. Spray Rinse

Manufacturers would likely employ a spray rinse at EL 1. Spray rinse significantly decreases the volume of water used during the rinse cycle. The clothes washers at the baseline level use a deep rinse, during which the tub is filled with water to a level in which the clothes are submerged, agitated, and then drained to remove soap suds. A spray rinse uses high-pressure jets of water to rinse the load while the basket is spinning, without requiring the clothes to be immersed in water.

2. Increased Capacity

Unlike the top-loading standard product class, manufacturers have limited opportunity to increase capacity on top-loading compact units because they are limited, by definition, to an upper bound of 1.6 cubic feet. However, DOE believes that minor changes to the tub geometry could be made to increase capacity to 1.59 cubic feet.

3. Eliminate Warm Rinse

DOE believes that manufacturers are likely to eliminate the warm rinse feature at EL 1 in order to achieve the required MEF.

4. Reduced Water Temperatures

DOE believes that manufacturers would likely reduce the hot and warm wash temperatures at EL 1. DOE observed that in general, the baseline compact top-loading clothes washer uses hot and warm wash temperatures much higher than the baseline standard-size top-loading clothes washer. DOE believes that manufacturers could reduce the hot and warm wash temperatures to the same temperatures used by standard-size clothes washers without negatively affecting wash performance or consumer utility.

MEF Efficiency Level 2

Based on energy and water consumption modeling using the design option approach and discussions with manufacturers, DOE believes that EL 2 could be achieved with the following changes:

1. Electronic Controls

Manufacturers would likely use all electronic controls in an EL 2 clothes washer. This includes a control board for the user interface, with a numerical display, and a main control board. Electronic controls would likely be required as a prerequisite for the additional design options used at this efficiency level.

2. Improved Fill Level Control

DOE believes manufacturers would likely offer automatic fill controls at EL 2. This includes switching to an electronic pressure transducer with embedded control logic, and adding a flowmeter. The electronic pressure sensor and control logic would allow the clothes washer to determine the load size based on the measured volume of water introduced to the clothes container and the transient water pressure measured at the bottom of the tub, which is affected by the load size. These controls would reduce excess water consumption by filling the wash basket with the minimum volume of water needed to soak the load.

3. Improved Temperature Control

To achieve EL 2, the temperature control scheme likely features a thermistor and four or five wash temperature set-points. More temperature set-points would help to reduce excess hot water, improving efficiency.

4. More Efficient Motor

A more efficient motor would likely replace the standard two-speed PSC motor. A motor that is roughly three times more efficient than the motor used in the baseline model would likely be required to achieve the required MEF at EL 2. The motor would also be required to support significantly higher spin speeds.

5. Stainless Steel Wash Basket

Manufacturers would likely switch construction of the wash basket from enameled cold rolled steel to stainless steel at EL 2. According to interviews with manufacturers, stainless steel wash baskets are able to tolerate higher spin speeds, which yield lower RMC values. Switching to a stainless steel wash basket, in addition to an improved motor and a lid-locking assembly, would allow clothes washers to reach spin speeds of up to 1000 RPM.

6. Water Recirculation

DOE believes that manufacturers would likely use a recirculation pump at EL 2 to decrease water consumption. Recirculation pumps take water from the bottom of the wash tub back to the top to help ensure effective washing throughout the wash basket.

Front-Loading Compact Clothes Washers

MEF Efficiency Level 1

Based on energy and water consumption modeling using the design option approach, DOE believes that EL 1 could be achieved with the following changes:

1. Improved Fill Level Control

As seen for front-loading standard clothes washers, one method used to improve water flow control is to incorporate an electronic pressure sensor. DOE believes that an electronic pressure sensor would be used to improve water fill level control at EL 1.

2. Low Standby Power Control Board

To achieve additional low-cost improvement in efficiency, manufacturers would likely use a switch mode power or transformerless power supply on the control board. These design options are described in more detail in the following section.

5.6.3.6 Standby Mode Construction

As part of the reverse-engineering analysis, DOE investigated the design options and incremental manufacturing costs for decreasing standby power consumption. DOE developed the following design pathways for the standby levels identified in section 5.4.4.

DOE's analysis suggests that SL 1 can be achieved by implementing a switch-mode power supply in place of a conventional linear regulated control board power supply. DOE observed a number of clothes washers that incorporated switch-mode power supplies. DOE's analysis also suggests that SL 2 can be achieved by implementing a transformerless power supply along with a conventional power supply. Such a power supply design, incorporated with a "soft" power pushbutton and electromechanical relay, would provide just enough power through the transformerless power supply to maintain the microcontroller chip while the clothes washer is not powered on. When the power button is pressed, the control logic enables a Triode for Alternating Current (Triac) to enable power to the transformer of the linear power supply. Hence, the Triac isolates the linear power supply from the mains until it is needed to power relays, the user interface, etc. Through this means, the standby power issues typically associated with linear power supplies can be nearly eliminated.

5.6.4 Cost-Efficiency Curves

5.6.4.1 Active Mode Incremental Costs

Based upon product teardowns and cost modeling, DOE developed the following active mode cost-efficiency relationships for top-loading standard and front-loading residential clothes washers. DOE used these curves to supplement and validate the incremental cost information provided by AHAM, as discussed in section 5.6.1. The corresponding cost-efficiency curves are shown as follows.

Top-Loading Standard

For top-loading standard clothes washers, DOE developed incremental manufacturing costs by tearing down units, and creating a cost model at each efficiency level. DOE started with the baseline unit cost model, and at each higher efficiency level, added in the observed changes associated with improving efficiency. By doing this, DOE excluded the costs of any non-efficiency related components from the more efficient units. The more efficient units are generally sold at a higher price point, and sometimes include more complex displays or other user interface features that are not necessarily efficiency-related. Table 5.6.14 and Figure 5.6.14 show the incremental manufacturing costs from DOE's reverse-engineering analysis and from the AHAM data submittal. These costs do not include costs related to reducing standby power consumption, which are discussed in the next section. The AHAM data submittal for top-loading clothes washers did not include EL 6 because EL 5 was the max-tech level on the market at the time the data was submitted.

Table 5.6.14 Top-Loading Standard Clothes Washer Incremental Manufacturing Costs Based on MEF

Efficiency Level (MEF, ft^3/kWh)	Incremental Costs *($2010)*	
	AHAM	DOE
Baseline (1.26)	-	-
EL 1 (1.40)	$3.10	$4.43
EL 2 (1.72)	$8.40	$23.79
EL 3 (1.80)	$13.00	$71.67
EL 4 (2.00)	$24.00	$66.23
EL 5 (2.26)	$59.20	$80.05
EL 6 (2.47)	N/A	$68.30

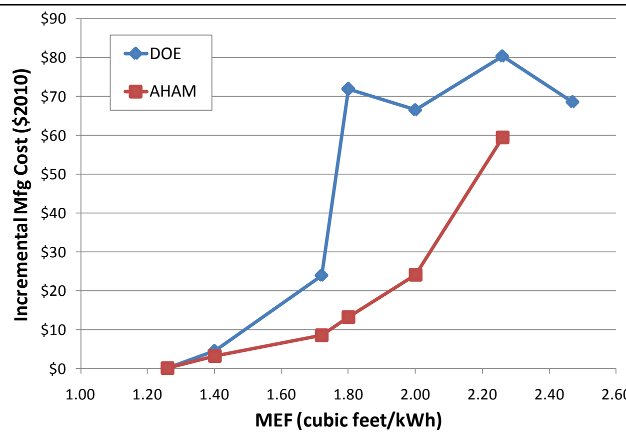

Figure 5.6.14 Top-Loading Standard Clothes Washer Cost-Efficiency Curves Based on MEF

Table 5.6.14 and Figure 5.6.14 clearly show that the DOE incremental costs are generally higher than the AHAM-submitted costs. DOE is confident in its estimates of the incremental costs for the units it torn down. However, DOE is aware that these values are only representative of the small number of units torn down, and do not necessarily characterize the entire top-loading residential clothes washer market nor the expected typical costs at the time of the effective date of new standards. The AHAM data is aggregated from multiple manufacturers, and DOE believes this provides a better representation of the actual incremental costs manufacturers would experience. Because the AHAM incremental costs are generally lower than the DOE-developed costs, DOE believes manufacturers may be aware of additional methods to increase efficiency at a lower cost than the technology options observed in the reverse engineering analysis. For these reasons, DOE chose to use the AHAM-submitted incremental costs, adjusted to be expressed in terms of IMEF, as the basis for the subsequent top-loading analyses described in the later chapters of this TSD. Because the AHAM data submittal did not include an incremental cost figure for EL 6, DOE used the incremental cost derived from its teardown of the max-tech unit for the EL 6 data point.

Front-Loading Standard

For front-loading clothes washers, DOE tore down units at all efficiency levels, except for the baseline because DOE is unaware of any front-loading clothes washers available at that level.

DOE observed that manufacturers each have unique baseline units depending on their segment of the market. For example, manufacturers producing models only at higher efficiency levels will tend to have a higher efficiency baseline unit; an incremental cost compared to the overall baseline unit is therefore not representative of the actual incremental costs that such a manufacturer would expect. To account for this, DOE developed incremental cost curves for each manufacturer according to their respective baseline units. For a manufacturer only producing front-loading clothes washers at higher efficiency levels, the incremental costs associated with the efficiency levels below that manufacturer's baseline is assumed to be zero. A single cost-efficiency curve was then calculated from a market share-weighted average of the individual curves. The DOE incremental costs shown in Table 5.6.15 and Figure 5.6.15 show the market share-weighted average of the incremental cost curves.

Table 5.6.15 Front-Loading Clothes Washer Incremental Manufacturing Costs Based on MEF

Efficiency Level (MEF, ft^3/kWh)	Incremental Costs *($2010)*	
	AHAM	**DOE**
Baseline (1.72)	-	-
EL 1 (1.80)	$2.01	$0.00
EL 2 (2.00)	$5.02	$3.88
EL 3 (2.20)	$16.07	$23.53
EL 4 (2.40)	$39.18	$35.48
EL 5 (2.60)	N/A*	$51.44
EL 6 (2.89)	$72.33	$63.73 (MEF = 2.82**)

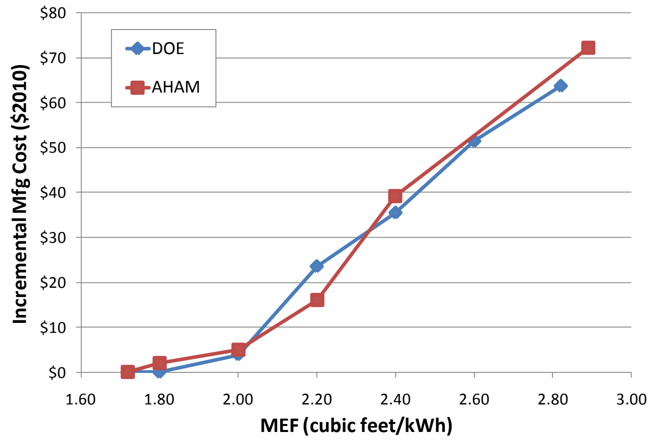

Figure 5.6.15 Front-Loading Standard Clothes Washer Cost-Efficiency Curves Based on MEF

*The AHAM data submittal did not include an incremental cost for EL 5 because DOE did not propose an efficiency level at 2.6 MEF in the August 2009 Framework Document.
**At the time DOE conducted its teardowns, the highest-efficiency clothes washer that was commercially available for purchase had MEF=2.82.

Table 5.6.15 and Figure 5.6.15 show that the DOE incremental cost estimates closely match the AHAM-submitted values. Therefore, DOE believes the AHAM data points provide an accurate representation of the incremental costs manufacturers would likely incur to reach the different efficiency levels. For these reasons, DOE based its front-loading analyses described in the later chapters of this TSD on the AHAM-submitted incremental costs, adjusted to be expressed as IMEF.

Top-Loading Compact

For top-loading compact clothes washers, DOE used a design option approach to model the cost of the design options that would likely be required to achieve each higher efficiency level. DOE started with the baseline unit cost model, which it developed during the teardown analysis, and added in estimates of the likely changes associated with improving efficiency. Table 5.6.16 and Figure 5.6.16 show the incremental manufacturing costs from DOE's design option analysis.

Table 5.6.16 Top-Loading Compact Clothes Washer Incremental Manufacturing Costs Based on MEF

Efficiency Level (MEF, *ft³/kWh*)	Incremental Costs *($2010)*
	DOE
Baseline (0.77)	-
EL 1 (1.26)	$5
EL 2 (1.81)	$45

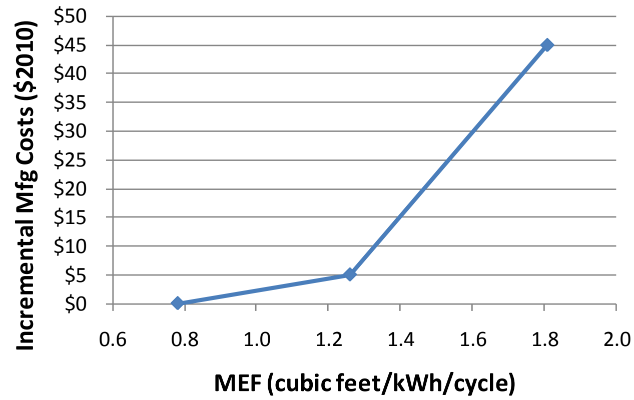

Figure 5.6.16 Top-Loading Compact Clothes Washer Cost-Efficiency Curves Based on MEF

Front-Loading Compact

For front-loading compact clothes washers, DOE used a design option approach to model the cost of the design options that would likely be required to achieve the higher efficiency level. DOE started with a baseline cost equivalent to the baseline cost for the front-loading standard product class and added in estimates of the likely changes associated with improving efficiency. Table 5.6.17 and Figure 5.6.17 show the incremental manufacturing costs from DOE's design option analysis.

Table 5.6.17 Front-Loading Compact Clothes Washer Incremental Manufacturing Costs Based on MEF

Efficiency Level (MEF, *ft³/kWh*)	Incremental Costs *($2010)*
	DOE
Baseline (1.60)	-
EL 1 (1.72)	$3

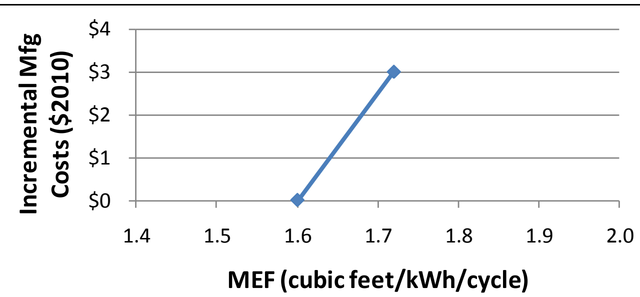

Figure 5.6.17 Front-Loading Compact Clothes Washer Cost-Efficiency Curves Based on MEF

5.6.4.2 Standby Mode Incremental Costs

Based upon the product teardowns and cost modeling, DOE developed the incremental costs associated with decreasing standby power consumption, shown in Table 5.6.18. DOE did not receive data from AHAM regarding the incremental costs associated with the different standby power levels. These incremental costs are atypical because the highest efficiency level (SL2) is less expensive than SL1. This occurs because the switch-mode power supply used in SL1 is more expensive than the additional transformerless drop-cap power supply added to the traditional linear power supply in SL2.

Table 5.6.18 Standby Power Incremental Manufacturing Cost

Standby Power Level *(W)*	**Description**	**Incremental Cost** *($2009)*	**Incremental Cost** *($2010)*
Baseline (2.3)	Traditional linear power supply	$0	$0
SL 1 (1.7)	Switch-mode power supply	$3.90	$3.92
SL 2 (0.08)	Traditional linear power supply with additional transformerless drop-cap power supply and microcontroller	$1.17	$1.17

5.6.4.3 IMEF Incremental Costs

DOE subsequently developed cost-efficiency relationships based on IMEF. As noted in section 5.4.5, DOE developed conversion formulas to translate MEF efficiency levels into IMEF efficiency levels, taking into consideration all the significant amendments in the test procedure. The IMEF cost-efficiency curves also incorporate standby power options into the MEF efficiency levels where DOE determined them to be most cost effective. Table 5.6.19 and Figure 5.6.18 present DOE's estimates of the incremental manufacturing cost associated with improving IMEF above the baseline for top-loading standard-size clothes washers. These curves are derived from the AHAM data submittal and incorporate the additional costs in Table 5.6.18 associated with standby power reduction.

DOE used the AHAM-derived incremental manufacturing costs at the calculated IMEF efficiency levels as described in Table 5.6.19 and

Table 5.6.20 in its subsequent analyses detailed in this TSD.

Table 5.6.19 Top-Loading Standard Clothes Washer Incremental Manufacturing Costs Based on IMEF

Integrated Efficiency Level	MEF (ft^3/kWh)	IMEF (ft^3/kWh)	Incremental Costs *($2010)*
Baseline	1.26	0.84	$0
EL 1	1.40	0.98	$3.11
EL 2	1.72	1.29	$8.44
EL 3	1.80	1.34	$13.06
EL 4	1.80	1.34	$16.98
EL 5	1.80	1.37	$14.24
EL 6	2.00	1.57	$25.29
EL 7	2.26	1.83	$60.65
EL 8	2.47	2.04	$69.79

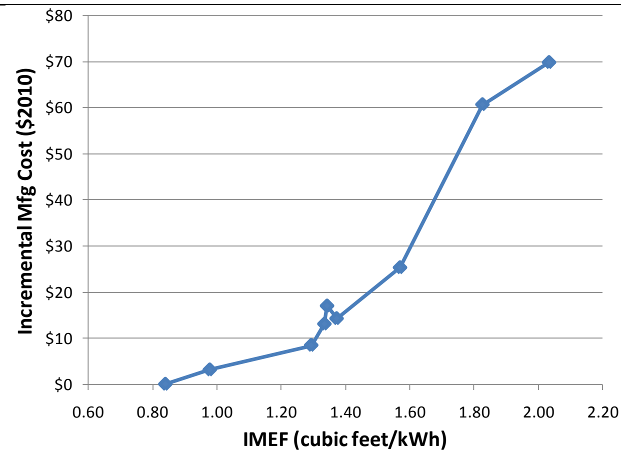

Figure 5.6.18 Top-Loading Standard Clothes Washer Cost-Efficiency Curves Based on IMEF

Table 5.6.20 and Figure 5.6.19 present DOE's estimates of the incremental manufacturing cost associated with improving IMEF above the baseline for front-loading standard-size clothes washers. Like the top-loading curves, these curves are derived from the AHAM data submittal and incorporate the additional costs in Table 5.6.18 due to standby power reduction.

Table 5.6.20 Front-Loading Standard Clothes Washer Incremental Manufacturing Costs Based on IMEF

Integrated Efficiency Level	MEF (ft^3/kWh)	IMEF (ft^3/kWh)	Incremental Costs *($2010)*
Baseline	1.72	1.37	$0
EL 1	1.72	1.39	$3.92
EL 2	1.72	1.41	$1.18
EL 3	1.80	1.49	$3.18
EL 4	2.00	1.66	$6.20
EL 5	2.20	1.84	$17.25
EL 6	2.40	2.02	$40.36
EL 7	2.60	2.20	$53.88
EL 8	2.89	2.46	$73.51

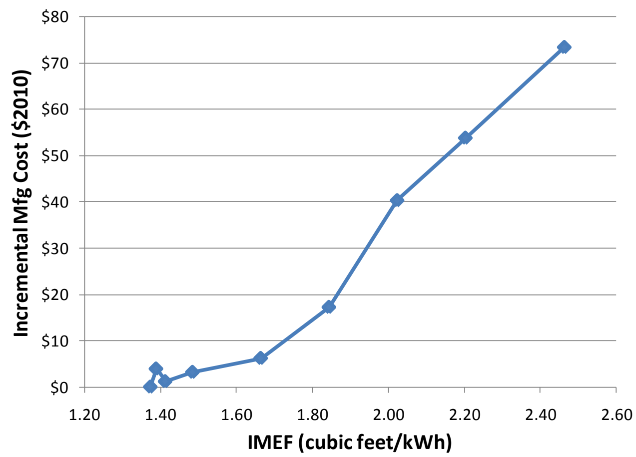

Figure 5.6.19 Front-Loading Standard Clothes Washer Cost-Efficiency Curves Based on IMEF

Table 5.6.21 and Figure 5.6.20 present DOE's estimates of the incremental manufacturing cost associated with improving IMEF above the baseline for top-loading compact-size clothes washers.

Table 5.6.21 Top-Loading Compact Clothes Washer Incremental Manufacturing Costs Based on IMEF

Integrated Efficiency Level	MEF (ft^3/kWh)	IMEF (ft^3/kWh)	Incremental Costs *($2010)*
Baseline	0.77	0.59	-
EL 1	1.26	0.86	$5
EL 2	1.81	1.15	$45

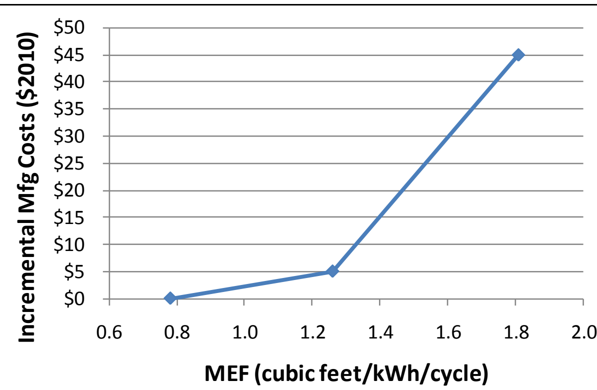

Figure 5.6.20 Top-Loading Compact Clothes Washer Cost-Efficiency Curves Based on IMEF

Table 5.6.22 and Figure 5.6.21 present DOE's estimates of the incremental manufacturing cost associated with improving IMEF above the baseline for front-loading compact-size clothes washers.

Table 5.6.22 Front-Loading Compact Clothes Washer Incremental Manufacturing Costs Based on IMEF

Integrated Efficiency Level	MEF (ft^3/kWh)	IMEF (ft^3/kWh)	Incremental Costs *($2010)*
Baseline	1.60	1.03	-
EL 1	1.72	1.13	$3

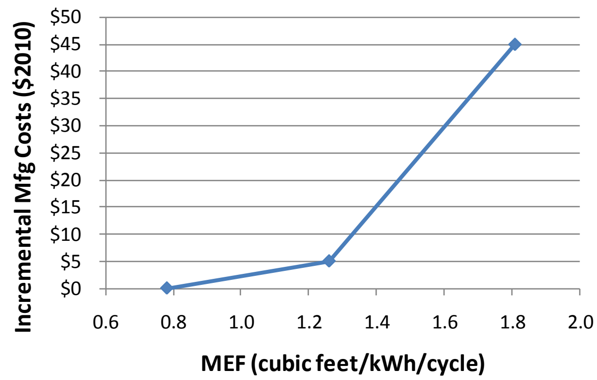

Figure 5.6.21 Front-Loading Compact Clothes Washer Cost-Efficiency Curves Based on IMEF

5.6.5 Manufacturer Interviews

DOE conducted interviews with residential clothes washer manufacturers to develop a better understanding of current product features and the technologies used to improve energy efficiency. The questionnaires used to conduct these interviews are contained in appendix 5C of this TSD. The manufacturers interviewed represent a wide range of U.S. market share and included both domestic and international companies that sell residential clothes washers in the United States. During these interviews, DOE asked manufacturers questions about the following topics:

- Product classes
- Design features of current baseline products
- Proposed incremental efficiency levels
- Design options required to meet each efficiency level
- Technical details about each design option
- Installation and repair costs as a function of efficiency
- Relationship between MEF and WF
- Test procedure issues

The discussion helped DOE understand what proposed design options have already been implemented and what additional design options DOE should consider. In addition, DOE conducted discussions regarding issues with the DOE clothes washer test procedure. The discussion below represents a consolidation of the responses.

5.6.5.1 Product Classes

All manufacturers supported the elimination of the top-loading semi-automatic and suds-saving product class categories because these products no longer exist in the marketplace.

Manufacturers were divided on whether to retain the distinction between top-loading standard and front-loading product classes and whether the same distinctions should apply to compact clothes washers.

5.6.5.2 Design Features of Current Baseline Products

Manufacturers identified the following features that are typically found in baseline top-loading and front-loading washers, shown in shown in Table 5.6.23.

Table 5.6.23 Features Typically Found in Baseline Units

Top-Loading	Front-Loading
Electromechanical controls	Electronic controls
Single-speed motor	Variable-speed motor
Transmission	Belt & pulley drive system
Wash basket (enameled steel)	Wash basket (stainless steel)
Outer tub (plastic)	Outer tub (plastic)
Traditional agitator	Wash basket paddles
Simple ratio valves for hot/cold water	Simple ratio valves for hot/cold water
Drain pump	Drain pump
Pressure switch allowing 3-5 water levels	Simple pressure switch
Deep water fill	Front door and bellows assembly
Deep water rinse	Counterbalance mass
Moderate spin speeds	

5.6.5.3 Active Mode Efficiency Levels

DOE asked manufacturers to comment on the proposed active mode efficiency levels presented in the framework document for top-loading standard and front-loading product classes. Manufacturers were asked to comment on the appropriateness of each incremental efficiency level, including the gap-fill levels and the max-tech levels. In general, the responses from manufacturers were consistent with the comments received after the framework meeting.

5.6.5.4 **Design Options Required to Meet each Active Mode Efficiency Level**

DOE asked manufacturers to describe the changes associated with each active mode efficiency level relative to the baseline units in each product class. Table 5.6.24 presents a list of technologies that manufacturers currently use or are considering using to achieve each incremental active mode efficiency level in top-loading residential clothes washers. At the time the interviews were conducted, the max-tech level for top-loading clothes washers corresponded to EL 5. Therefore, no details were provided by manufacturers for EL 6.

Table 5.6.24 Design Options Required To Meet Top-Loading Standard Efficiency Levels

Efficiency Level	MEF	WF	Technology Options
EL 1	1.40	9.5	Adaptive fill technology Bi-metal temperature control Flow-control water valves Motor efficiency improvement Spray rinse
EL 2	1.72	8.0	Agitator modification Basket shape modification Electronic controls Higher spin speeds Larger capacity Load-size sensors More advanced water inlets Spray rinse Stainless steel basket Variable-speed drive Water temperature sensors (thermistors)
EL 3	1.80	7.5	Higher spin speeds Larger capacity Pressure switch accuracy improvement Stronger basket
EL 4	2.00	6.0	Adaptive fill technology Agitator replaced by impeller High suspension Higher spin speeds Larger capacity Longer cycle times Lower water temperatures More mechanical action More sensing technology More sophisticated electronic control Out-of-balance detection Recirculation pumps Stainless steel basket
EL 5	2.26	4.48	Absorption sensors Accelerometers Better motor Better temperature control Gray-water rinse Higher capacity Higher chemical concentration Highest spin speeds Load-composition sensors Longer cycle times More mechanical action More robust suspension system Most sophisticated load detection Tachometer Water flow meters
EL 6	2.47	3.60	No information provided by manufacturers

Table 5.6.25 presents a list of technologies that manufacturers currently use or are considering using to achieve each incremental active mode efficiency level in front-loading residential clothes washers. No information was provided by manufacturers for EL 5 because DOE was not considering that efficiency level at the time the manufacturer interviews were conducted.

Table 5.6.25 Design Options Required to Meet Front-Loading Standard Efficiency Levels

Efficiency Level	MEF	WF	Technology Options
EL 1	1.80	7.5	No changes necessary
EL 2	2.00	6.0	Electronic user interface
EL 3	2.20	4.5	Sophisticated damping system Analog pressure sensors Water flow meter Higher spin speeds Longer cycle time Reinforced structure Larger capacity
EL 4	2.40	4.2	Larger capacity Recirculation pump Better control technology
EL 5	2.60	2.20	No information provided by manufacturers
EL 6	2.89	3.20	More precise dispensing of chemicals Load-size sensors Fuzzy logic

5.6.5.5 **Technical Details About Each Design Option**

DOE asked manufacturers to provide technical details on each design option identified in the framework document. This included estimating the energy efficiency improvement potential of each design option. The sections below summarize the manufacturers' comments on each design option.

Adaptive Control Systems

The use of adaptive control systems varied among manufacturers. Some manufacturers reported no use of adaptive control systems. Others reported limited use, such as water temperature feedback. A small number of manufacturers reported using sophisticated adaptive control systems to perform functions such as sensing load size and composition. Sensors commonly used for these functions include thermistors, Hall-effect sensors, pressure sensors, water flow meters, electrodes, and feedback from the motor. Parameters that are adjusted based on sensor input include water level, wash profile, length of wash, and rinse type.

Turbidity sensors, commonly used in dishwashers to sense water clarity, are not used by any manufacturers interviewed in residential clothes washers. All manufacturers indicated that turbidity sensors are ineffective because of the level of suds commonly present in U.S. clothes washers. Also, if a only single garment has a strong stain while the rest of the load is relatively clean, the wash water will appear also clean even though the stain has not been completely removed. In this case the turbidity sensor would incorrectly make the clothes washer select a cycle that may not result in the stain being lifted.

Added Insulation

All manufacturers stated that there is no significant potential efficiency improvement from adding insulation to the outer tub. The vast majority of residential clothes washers for sale in the United States incorporate a plastic tub, which has a low thermal mass. In the United States, most hot water is pre-heated outside the clothes washer, and the internal heat loss is negligible. Additionally, in most washers the proportion of hot wash water cycles is relatively small, while most cycles use either cold or lukewarm wash and/or rinse cycles, resulting in very little or no benefit for insulation.

Advanced agitation concepts for vertical-axis machines

Several manufacturers use low-profile agitators, nutating plates, or impellers, in their high efficiency vertical-axis top-loading machines. Using a low-profile agitator increases the usable capacity of a clothes washer and hence can significantly improve both MEF and WF.

Automatic Fill Control

Every manufacturer interviewed uses some type of automatic fill control in at least some of their units. These are used in both top-loading and front-loading clothes washers. Low-end systems use simple on/off switches. More advanced systems use pressure transducers, which cost more than the simple on/off pressure switch.

Bubble Action

The large majority of manufacturers have not considered this technology. Bubble action washers rely on generating bubbles to assist the mechanical agitation, reduce water consumption, and to more evenly distribute detergent throughout the clothing. No manufacturer currently ships a bubble-action clothes washer in the United States, and manufacturers were divided regarding the actual energy efficiency benefits of bubble-action clothes washers.

Direct Drive Motor

Approximately half of the manufacturers interviewed use direct-drive motors on some or all of their clothes washer models. Manufacturers currently use, or stated they would use in the future, brushless direct current (BLDC) and brushless permanent magnet (BPM) direct-drive motors. Direct-drive motors can have an almost infinite amount of wash profiles, which can help provide efficiency improvements

Electrolytic disassociation of water

None of the manufacturers currently use this technology in the United States. One manufacturer noted that this technology is used in Japan and Korea. Several manufacturers have considered this technology, but have determined that potential efficiency savings are not worth the added cost.

Horizontal-axis design

All manufacturers of horizontal-axis clothes washers generally agreed with DOE's estimate that horizontal-axis machines use on average 40 percent less energy and 25 percent less water than traditional vertical-axis washers.

Horizontal-axis design with recirculation

Recirculation may or may not offer much if any benefit according to the manufacturers queried. Vertical-axis clothes washers typically have a larger sump and hence may benefit more from recirculating water from the sump into the wash basket.

Hot water circulation loop

All manufacturers agreed that implementing a hot water circulation loop, which would involve a heat exchanger, may be technically possible but would provide little if any efficiency gains and would be prohibitively expensive.

Improved fill control

Improved fill control would require a high-end pressure switch or a more expensive pressure transducer, which would require an electronic controller to interpret the analog signal being sent by the transducer.

Improved horizontal-axis washer drum design

Manufacturers generally agreed that there is little room for efficiency improvements by changing the design of the washer drum.

Improved water extraction to lower remaining moisture content

The manufacturers interviewed currently have RMC values ranging from 39–55 percent for top-loading clothes washers and 30–40 percent for front-loading clothes washers. One manufacturer stated that 30-percent RMC is considered the lowest possible value that does not significantly increase the risk of laundry damage due to the higher spin speeds necessary.

Multiple manufacturers stated that increasing the spin speed offers the greatest potential for energy efficiency improvements. Current top-load spin speeds range from 350–1100 RPM. Current front-load spin speeds range from 1150–1600 RPM. Several manufacturers stated that increasing spin speeds would require stronger motors, better off-balance detection and prevention, and stronger structural support. Containing catastrophic failures of wash baskets during the spin cycle may also require additional reinforcements to the existing exterior wrapper structure.

Multiple manufacturers stated that that longer spin cycles offer decreasing returns on improving energy efficiency.

Multiple manufacturers stated that changing the direction of rotation of the spin cycle does not have any significant effect on the energy efficiency of either top-loading clothes washers or front-loading clothes washers. All manufacturers generally agreed that there is little, if any, potential efficiency gains to be made by adjusting the number or size of holes in the wash basket. However, hole diameters in the wash basket have to be kept small enough to prevent clothes from being extruded through them during the spin cycle.

Increased motor efficiency

Two manufacturers stated that a direct-drive motor with newer drive train technologies could decrease motor energy usage by 50 percent, which would correspond to roughly 5-percent increase in overall efficiency. Other manufacturers stated that motor efficiency improvements would be less, ranging from 10–40 percent of motor energy usage. The cost estimates for a more advanced motor ranges from $5–30 over a traditional motor. One manufacturer stated that switching motors would require $1 million in capital expenses for new drive electronics and upgrades to the existing mounting system.

Low standby power design

All manufacturers stated that standby power is consumed by electronic components including displays, sensors, microprocessors, noise filters, and the internal power supply.

Manufacturers stated that they use a variety of electronic display types, including LEDs, graphic LEDs, and liquid crystal display (LCD) screens. Standby power for electronic displays ranges from 1.0 to 5.0 W, depending on the type of display. Several manufacturers dim the electronic displays after a period of non-use. Some manufacturers also turn off the displays completely during non-use, which reduces standby power to near zero.

One option for reducing standby power is to use a switch-mode power supply rather than a traditional linear power supply. The large majority of manufacturers interviewed currently use switch-mode power supplies. Manufacturers were uncertain about the standby power savings or costs associated with using switch-mode power supplies.

Ozonated laundering

Multiple manufacturers noted that this technology has been used in Japan, Korea, and Europe. One manufacturer stated that ozone does kill bacteria, so this technology could be used instead of hot water or steam for sanitization. However, manufacturers generally agreed that ozone has the potential to degrade certain materials, particularly plastics and rubber gaskets, so materials in clothes washers would have to be upgraded to better handle ozone exposure.

Plastic particle cleaning

None of the manufacturers interviewed have considered plastic particle cleaning as a viable option. One manufacturer stated that the cleaning performance of this technology has not been proven, and the technology would require consumers to purchase and dispose of plastic pellets. The supply chain to support the technology does not exist today and would have to be developed. Consumer education would be another hurdle to implementation.

Reduced thermal mass

Most manufacturers interviewed currently use plastic wash tubs. Manufacturers generally agreed that there was no more room for improvement with reducing the thermal mass of the wash tub.

Spray rinse or similar water-reducing rinse technology

All the manufacturers that sell top-loading clothes washers reported using spray rinse technology in at least some of their top-loading clothes washers. One manufacturer stated that spray rinse uses one-third the water of a typical deep rinse, at essentially zero cost. Manufacturers stated that improvements in WF range from 0.4 to 2.0. Spray rinse is not used on front-loading washers and there may be some consumer acceptance/education hurdles to overcome.

Thermostatically controlled mixing valves

Several manufacturers reported using implementations that emulate thermostatically controlled water valves using standard solenoid-activated water valves. In general, the electronic controller cycles the valves based on water temperatures measured either inside the washer or within the water valve assembly. Thermostatically controlled mixing valves have the potential to save hot water based on the temperature of the hot water inlet. The tolerance on these valves ranges from ± 2 to ± 5 degrees Fahrenheit. These savings are unlikely to be realized under DOE test conditions since incoming water temperatures are strictly controlled.

Tighter tub tolerance

Manufacturers generally agreed that tub tolerances have been tightened significantly and are close to their practical limits. Suds lock is one of the factors limiting further decreases in the annulus between the wash basket and the wash tub. Another limiting factor is the tolerance that must be provided to accommodate any flexing of the wash basket that can occur during the spin cycle, especially with out-of-balance loads. Front-load washers also require enough clearance for an internal water heater, if equipped.

5.6.5.6 **Installation and Repair Costs as a Function of Efficiency**

Manufacturers' responses differed with respect to whether installation and repair costs vary as a function of clothes washer efficiency. Multiple manufacturers stated that neither installation nor repair costs varied as a function of efficiency. Multiple manufacturers stated that maintenance and repair costs may increase as efficiency increases, since higher efficiency machines tend to have more complex parts, with higher failure rates and higher replacement costs. Multiple manufacturers stated that installation costs may increase as a function of efficiency, as high efficiency machines have higher spin speeds, which may require the user to reinforce the floor or to install the washer on a pedestal.

Relationship between MEF and WF

Multiple manufacturers stated that the main shared characteristic between MEF and WF is the impact on both due to the drum capacity. Multiple manufacturers also stated that hot water consumption affects both MEF and WF; cold water consumption affects only WF; and spin speed affects only MEF. One manufacturer noted that in general, as MEF increases, WF decreases, but not linearly.

Test procedure issues

DOE asked manufacturers a number of questions regarding the current clothes washer test procedure. Their responses were considered in the recent test procedure rulemaking. Some of the comments received include the following:

- Capacity – Manufacturers expressed the need for DOE to clarify the capacity measurement technique for both top-loading and front-loading washers. Also, the test procedure should be modified to accommodate capacities up to 5 ft^3.
- Test cloth – Several manufacturers reported inconsistencies between lots of the test cloth. They recommended that DOE pursue ways of ensuring the consistency of future lots of test cloth.
- Performance – Several manufacturers stated that clothes washer standards have progressed to the point where they may start to have a negative impact on product performance. Some manufacturers suggested incorporating a measure of cleaning and rinsing performance into the standard.