

## CHAPTER 4. ENGINEERING ANALYSIS

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## CHAPTER 4. ENGINEERING ANALYSIS

### 4.1 INTRODUCTION

The Engineering Analysis determines the maximum technologically feasible energy efficiency level and develops cost-efficiency relationships to show the manufacturer costs of achieving increased efficiency. As described in this section, manufacturers were asked to provide clothes washer performance and manufacturing cost information to conduct the engineering analysis. Data was collected utilizing the efficiency-level approach. The clothes washer manufacturers remarked that this approach was the most suitable approach for showing the manufacturing cost of achieving increased efficiency while providing a high degree of confidentiality of design. This approach consists of letting manufacturers supply cost and corresponding efficiency data using any design option or design option combinations they choose. The collected information describes manufacturer specific costs of achieving predetermined efficiency levels. This format has the additional benefit of being entirely compatible with data requirements for the manufacturer impact analysis.

### 4.2 PRODUCT CLASSES

The Department DOE divides clothes washers into classes based on the size and features, e.g., suds saving. For the extant standards, DOE defines residential clothes washers in the following classes:

- top loading, compact (less than 1.6 cubic feet capacity);
- top loading, standard (1.6 cubic feet or greater capacity);
- top loading, semi-automatic;
- front loading; and
- suds saving.

For this rulemaking the Department has not analyzed compact, semi-automatic and suds saving product classes and therefore no engineering analysis was performed. All analyses was performed assuming a standard class, top loading, baseline efficiency washer.

### 4.3 BASELINE UNIT

A baseline unit is the starting point for analyzing design options for improving energy efficiency. In this engineering analysis, the baseline unit represents a typical model with an energy efficiency no lower than the minimum required by the amended National Appliance Energy Conservation Act (NAECA). New minimum standard for clothes washers (top loading, 1.6 cu.ft. or greater capacity) was set at Energy Factor (EF) = 1.18 cu.ft./kWh per cycle and became effective on May 14, 1994.

The Department issued two new test procedures in the *Federal Register* on August 27, 1997, during the course of this rulemaking: Appendices “J” and “J1” (62 FR 45484) which have been

incorporated into the Title 10 Code of Federal Regulations (CFR), Subpart B, Appendix J and J1.<sup>1</sup> The Engineering Analysis presented in this document is based on the Appendix J1 test procedure. This test procedure calculates a MEF (Modified Energy Factor) descriptor. Unlike its EF predecessor, the MEF uses remaining moisture content (RMC) to account for energy saved due to lower drying times and temperature use factors (TUFs). Using cloth loads and different water temperatures are among the many other substantive differences between the J and J1 test procedures. Given these different testing methods and variables, there is no computational relationship between the EF and MEF descriptors.

In order to determine the MEF value for the baseline unit, clothes washer manufacturers were asked to take a representative clothes washer with an EF as close as possible to 1.18 (current minimum EF) and perform the new J1 procedure. If no clothes washer was available with an EF value close to 1.18, they were asked to adjust the water volume, machine energy, and/or hot water volume to obtain an EF of 1.18. Five manufacturers (Amana, Frigidaire, GEA, Maytag and Whirlpool) submitted data to the Association of Home Appliance Manufacturers (AHAM). AHAM mathematically averaged these values to derive an industry average MEF value of 0.817 for the baseline unit (based on an EF=1.18).<sup>2</sup>

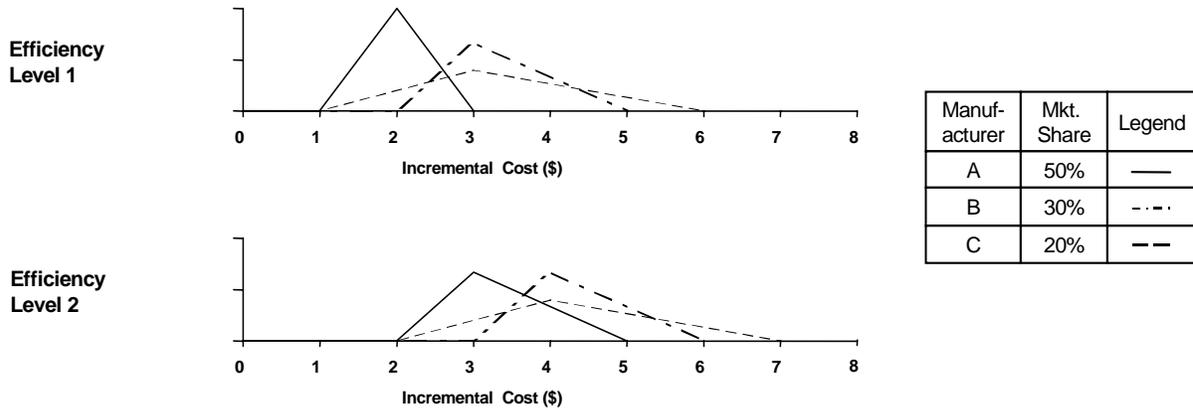
#### **4.4 COST-EFFICIENCY DATA COLLECTION**

Manufacturing cost and efficiency data was collected utilizing the efficiency level approach, in cooperation with AHAM. The manufacturers provided cost and corresponding efficiency data using any design option or design option combinations of their choice. The collected information describes manufacturer specific costs of achieving predetermined efficiency levels in addition to the energy-use characteristics. AHAM members provided costs and energy data for the following levels: Baseline (MEF=.817), 5% (MEF=.860), 10% (MEF=.908), 15% (MEF=.961), 20% (MEF=1.021) and 25% (MEF=1.089) improvement applied in an existing V-axis clothes washer and improvements of 35% (MEF=1.257), 40% (MEF=1.362), 45% (MEF=1.485), and 50% (MEF=1.634) applied in an H-axis clothes washer. Manufacturers believe that the disclosure of their individual costs is not practical given the proprietary nature of the information. Hence they agreed to provide detailed cost information to AHAM which would then aggregate this data and provide “industry” costs to DOE.

##### **4.4.1 Characterizing Uncertainty**

DOE requested that manufacturers provide a range of costs associated with achieving each efficiency level. Separate ranges were requested for variable and fixed costs. To characterize variable costs, each manufacturer was asked to provide its best point estimates (“most likely” values) for incremental material, labor and overhead costs to achieve a particular efficiency level. These disaggregated costs were then added to arrive at the “most likely” total variable cost for that manufacturer. In addition manufacturers were asked to indicate their maximum and minimum total variable costs to meet the efficiency level. Triangular distributions created using minimum, maximum, and “most likely” values were used to characterize the uncertainty associated with the manufacturing cost estimates. A similar procedure was adopted for fixed costs. Figure 4.1 shows

illustrative input distributions for incremental manufacturing costs. This figure assumes that data is provided by three manufacturers.



**Figure 4.1 Illustrative Input Distributions for Incremental Manufacturing Costs**

#### 4.4.2 Variability in Costs between Manufacturers

The Department requested disaggregated cost data from all manufacturers. Cost distributions, both variable and fixed, for the industry for achieving a particular efficiency level were obtained by applying shipment-based weights to each manufacturer’s cost distribution. This approach captures the richness of the data provided by manufacturers and ensures that the final cost distributions incorporate each individual manufacturer’s cost distributions thereby accounting for variability in the data submittals.

#### 4.4.3 Manufacturer Assumptions for Supplying Data

AHAM in conjunction with DOE proposed the following items to be used as data collection guidelines for manufacturers:

- Each incremental MEF above the baseline is viewed as the prospective future standard level. Thus the data entries for energy and costs are those necessary to convert 100% of the company’s production to that minimum standard level. Each incremental step is viewed as a separate entity. For example, if a company has some washing machines which already meet a new level above the baseline, then the costs shown represent the cost of converting the remainder of all machines.
- All MEF levels are obtained by using the Appendix J1 test procedure. Whereas, the baseline calculations assumed a warm-rinse, this is not the case with the projected levels. Manufacturers may use whatever means they wish to achieve the individual levels.
- Cost and efficiency data may have some incremental “step”-type function. Thus, companies

may know of technology that would enable them to reach a 20% improvement in efficiency, but may not have the technology available to reach a 15% efficiency level. In this case, the costs and efficiency improvements for the 20% level would be entered into the line for both the 15% and 20% improvements.

- Companies may use information on product costs, capital and tooling, or factory improvements which have already been incurred. If a company has made product improvements to energy efficiency as a result of the May 14, 1991, Final Rule and anticipated future energy standards in excess of those implemented on May 14, 1994, then these costs may be used to develop the efficiency and costs for this data collection exercise. In this case, companies have been asked to use information on costs incurred that directly relate to energy efficiency improvements in excess of the 1994 standard. Companies may use this information as a basis with which to calculate conversion of 100% of their production to that minimum standard level, according to the levels shown in the accompanying chart.

DOE worked with AHAM in developing a survey instrument which was then sent out by AHAM to manufacturers requesting detailed cost and energy-use data for each efficiency level. The energy and water-use data for the industry was obtained by applying shipment-weights to each manufacturer's data. This data is presented in Table 4.1.

**Table 4.1 Energy-use Data**

Product Characteristics				Energy Use			Water Use	
Percent Improvement	MEF <i>cu.ft/kWh/cycle</i>	Total Energy w/dryer <i>kWh/cycle</i>	Clothes Container <i>cu. ft.</i>	Hot Water <i>kWh/cycle</i>	Machine Energy <i>kWh/cycle</i>	Dryer Energy <i>kWh/cycle</i>	Water Use <i>gal/cycl</i>	Water Use <i>gal/cu. Ft.</i>
[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]
Baseline	0.817	3.227	2.847	1.587	0.209	1.43	39.181	13.779
5	0.860	3.165	2.817	1.543	0.209	1.413	38.613	13.732
10	0.908	3.017	2.822	1.408	0.209	1.4	38.613	13.71
15	0.961	2.833	2.832	1.216	0.209	1.407	38.621	13.67
20	1.021	2.739	2.893	1.113	0.218	1.408	38.446	13.342
25	1.089	2.292	2.866	0.715	0.304	1.273	26.6	9.22
35	1.257	1.866	2.749	0.462	0.133	1.27	21.03	7.601
40	1.362	1.859	2.749	0.462	0.133	1.263	21.03	7.61
45	1.485	1.651	2.736	0.429	0.114	1.107	23.405	8.57
50	1.634	1.574	2.736	0.413	0.114	1.047	23.405	8.57

For data in columns [3], [4], [5], [6],[7],[8], and [9], companies were asked to approximate the energy component that they would use to develop the MEF shown in column [2]. Where this data includes multiple products with varying clothes container capacities, for instance, a shipment weighted average within the product mix could be used.

#### 4.5 DATA AGGREGATION

The Department prepared a spreadsheet to aggregate cost data obtained from the manufacturers. AHAM used this spreadsheet and transmitted the results to DOE. This procedure helped address manufacturer concerns on the possible disclosure of proprietary manufacturing costs. The aggregation spreadsheet was developed using Microsoft Excel and Crystal Ball™ software.

The following procedure is used to arrive at the industry incremental total variable cost distribution for a particular efficiency level from individual manufacturers' cost submittals:

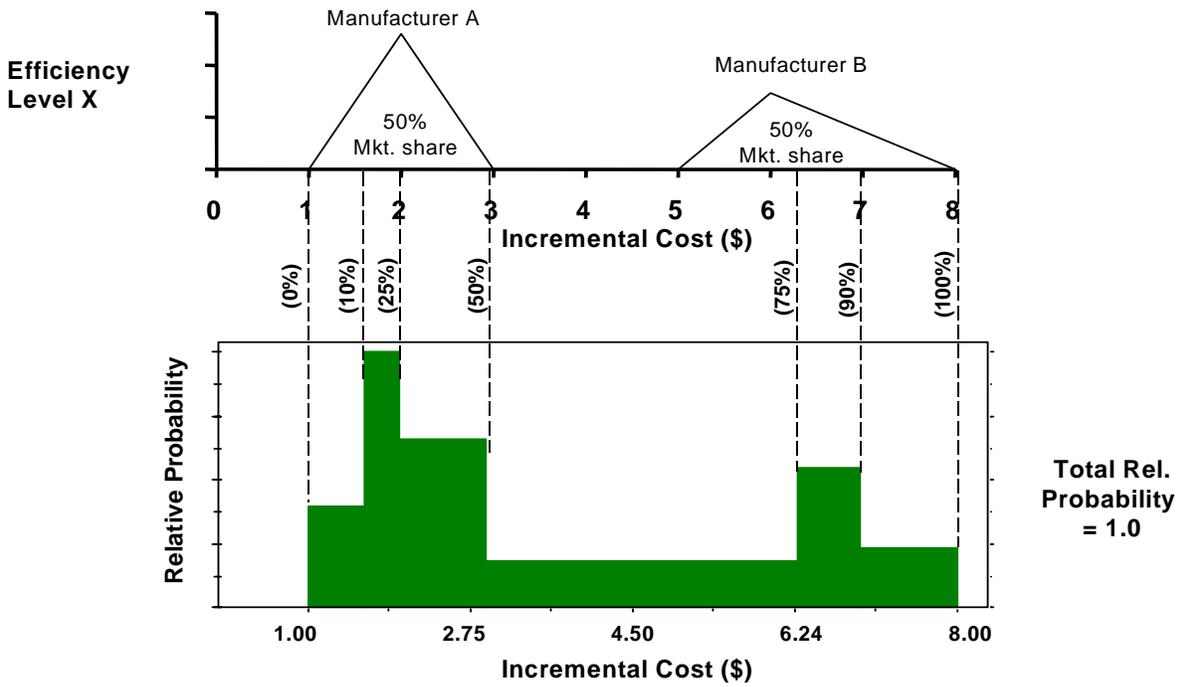
- Each manufacturer's incremental material, labor and tooling costs are added to arrive at the

- manufacturer's "most likely" incremental total variable cost.
- The "most likely" incremental total variable cost along with the minimum and maximum values of incremental total variable costs, as reported by manufacturers, are used to create a triangular distribution for the incremental total variable cost.
- Samples are drawn from each manufacturer's incremental total variable cost distributions to create an industry incremental total variable cost distribution. The number of times a particular manufacturer's cost distribution is sampled relative to others is dependent on its relative market share.

Figure 4.2 graphically illustrates individual manufacturers' incremental total variable cost distributions and the industry total incremental variable cost distribution thus obtained (here it is assumed that the industry is made up of two manufacturers each having a 50% market share).

The final cost distribution can also be presented using percentile values— 0, 10, 25, 50, 75, 90 and 100 percentiles. Crystal Ball™ software was used to specify individual distributions and to sample them to arrive at the final distribution. Crystal Ball™ provides the flexibility of reporting the final distribution graphically or by specifying percentile values. AHAM provided aggregated industry cost data using percentile values.

This procedure was used to arrive at the industry incremental total variable cost distribution for each efficiency level. Industry incremental total fixed cost distributions are obtained using the same steps as for the variable cost distribution. In addition, shipment weighted averages of the most likely costs, both fixed and variable, were calculated for each efficiency level as point values for incremental costs.



**Figure 4.2 Industry Cost Distribution Obtained by Sampling Each Manufacturer’s Cost Distributions**

The results after aggregation are presented in Tables 4.2 through 4.4. Table 4.2 gives the industry cost data using “most likely” values. Tables 4.3 and 4.4 present detailed cost distributions for total variable, total fixed, and incremental total manufacturing costs using percentile values.

**Table 4.2 Aggregated Cost Data using “Most Likely” Values**

Product Characteristics		Variable Costs per Unit			Total Variable	Total Fixed	Increm. Mfg. Cost	No. of Respondents
Percent Improvement	MEF <i>cu. ft./ kWh/cycle</i> (\$)	Materials (\$)	Labor (\$)	Overhead (\$)	Costs (\$ per Unit)	Costs (\$ per Unit)	(\$ per Unit)	
[1]	[2]	[12]	[13]	[14]	[15]	[22]	[23]	
Baseline	0.817							
5	0.860	0.01	0.01	0.00	0.02	0.07	0.09	5
10	0.908	0.25	0.04	0.01	0.30	0.61	0.91	5
15	0.961	3.18	0.10	0.04	3.32	1.01	4.33	5
20	1.021	10.71	(0.02)	1.80	8.89	6.21	15.10	5
25	1.089	36.14	8.61	0.09	44.84	19.29	64.13	5
35	1.257	86.73	10.94	7.78	105.45	22.72	128.17	5
40	1.362	87.15	10.94	7.78	105.87	22.72	128.59	5
45	1.485	125.58	15.52	14.51	155.61	24.67	180.28	4
50	1.634	132.40	15.68	14.51	162.59	24.67	187.26	4

For column [12], companies were asked to indicate incremental costs associated with materials that would be needed to achieve the particular standards levels in \$ per washer unit.

For column [13], companies were asked to indicate the incremental cost of labor associated with the new technology to reach the particular standard levels in \$ per washer unit.

For column [14], companies were asked to indicate the incremental overhead cost associated with this standard level. On column [14], for example, additional electricity to produce new components may be considered as overhead.

For each of these columns, entries on the baseline line are not necessary. However, companies that may have variable cost increases necessary to bring all production up to the minimum of MEF=0.817 were asked to include this cost in the 5% improvement line.

**Table 4.3 Industry Cost Distributions for 5%, 10%, 15% 20% and 25% Improvements Applied to an Existing V-axis Clothes Washer**

Product Characteristics			Total	Total	Incremental
Percent Improvement	Percentile	MEF cu.ft/kWh/cycle	Variable Costs (j) (\$ per Unit)	Fixed Costs (q) (\$ per Unit)	Manufacturing Costs (\$ per Unit)
Baseline		0.817			
5	100 (Max.)	0.860	0.24	0.87	1.11
	90		0.01	0.18	0.18
	75		0.01	0.01	0.02
	50		0.01	0.01	0.02
	25		0.01	0.01	0.02
	10		0.01	0.01	0.02
	6		0.00	0.00	0.00
10	100 (Max.)	0.908	6.75	10.84	12.84
	90		1.26	1.09	2.71
	75		0.49	0.30	0.96
	50		0.01	0.06	0.07
	25		0.01	0.05	0.06
	10		0.01	0.01	0.02
	0		0.00	0.00	0.00
15	100 (Max.)	0.961	40.00	10.84	46.19
	90		3.96	4.36	14.08
	75		0.76	0.30	0.97
	50		0.65	0.15	0.80
	25		0.58	0.12	0.72
	10		0.01	0.01	0.02
	0		0.00	0.00	0.00
20	100 (Max.)	1.021	70.00	20.60	79.45
	90		27.78	15.63	38.48
	75		14.13	11.75	27.74
	50		0.72	0.33	1.06
	25		0.65	0.26	0.95
	10		(0.53)	0.24	0.90
	0		(12.20)	0.21	0.80
25	100 (Max.)	1.089	83.28	27.630	102.63
	90		70.40	25.36	93.97
	75		67.24	24.04	90.85
	50		63.46	22.14	86.26
	25		15.11	14.39	29.37
	10		(0.30)	14.07	16.13
	0		(12.20)	4.85	1.28

**Table 4.4 Industry Cost Distributions for 35%, 40%, 45% and 50% Improvements Applied to a H-axis Clothes Washer**

Product Characteristics			Total	Total	Incremental
Percent Improvement (b)	Percentile	MEF <i>cu.ft/kWh/cycle</i>	Variable Costs (j) (\$ per Unit)	Fixed Costs (q) (\$ per Unit)	Manufacturing Costs (\$ per Unit)
Baseline		0.817			
35	100 (Max.)	1.257	280.00	101.60	381.60
	90		228.80	25.28	254.01
	75		118.63	23.29	143.34
	50		69.06	21.41	90.56
	25		63.59	19.44	85.30
	10		60.38	17.20	81.74
	6		52.03	15.06	67.43
40	100 (Max.)	1.362	290.00	101.60	391.60
	90		229.28	25.28	254.44
	75		117.17	23.30	143.57
	50		69.05	21.41	90.54
	25		63.73	19.44	85.28
	10		60.44	17.15	81.74
	0		52.03	15.06	67.43
45	100 (Max.)	1.485	300.00	101.60	401.60
	90		239.76	28.23	266.26
	75		227.29	23.70	251.73
	50		128.38	19.89	153.71
	25		79.38	18.02	97.37
	10		69.25	16.95	87.36
	0		52.30	15.06	68.26
50	100 (Max.)	1.634	300.00	101.60	401.60
	90		239.46	28.29	266.11
	75		227.31	23.76	251.70
	50		132.89	19.89	157.87
	25		95.45	18.00	113.81
	10		84.95	16.94	102.98
	0		66.16	15.06	82.12

The AHAM data submittal was used to develop a cost-efficiency graph. This graph is presented in Figure 4.3.

### AHAM Clothes Washer Data

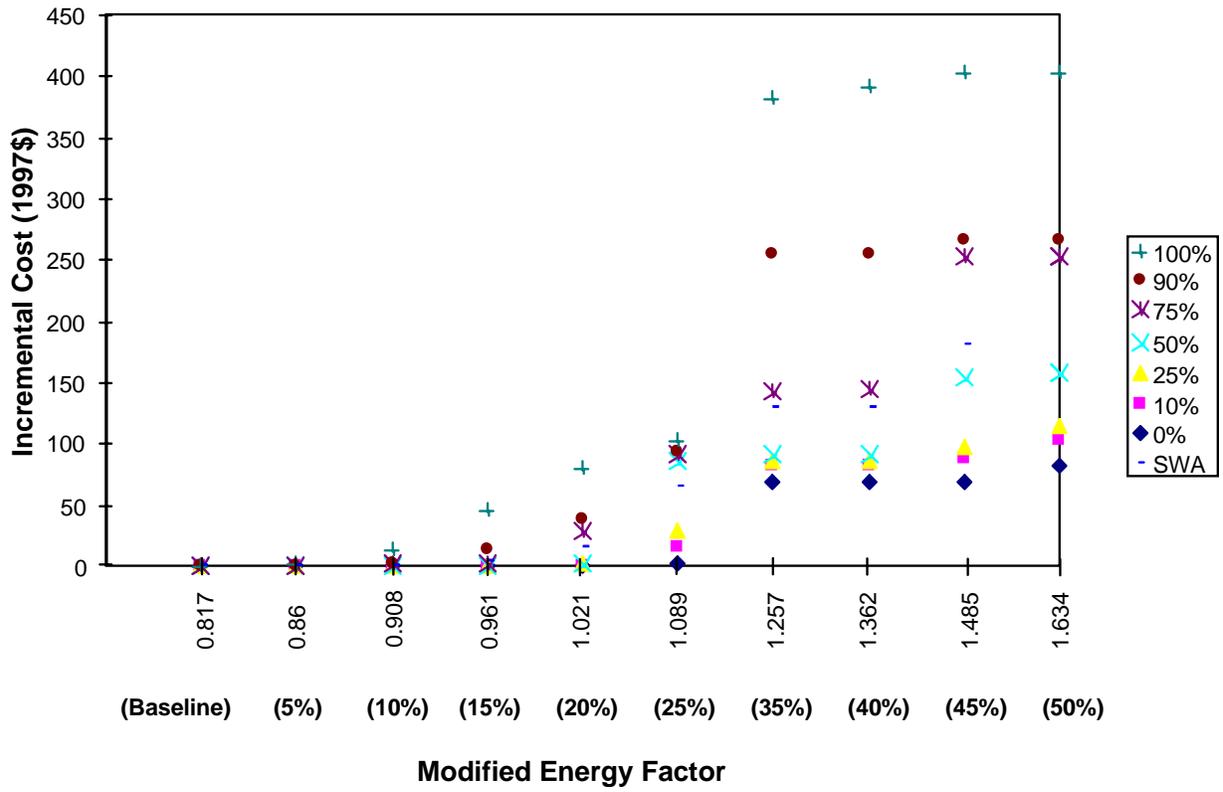


Figure 4.3 Cost-efficiency Graph for Clothes Washers

## REFERENCES

1. *Title 10, Code of Federal Regulations, Appendix J and J1 to Subpart B or Part 430--Uniform Test Method for Measuring the Energy Consumption of Automatic and Semi-automatic Clothes Washers*, January 1, 1999.
2. Morris, W., Technical Director for Regulatory Affairs, AHAM, *personal communication*. Letter to Bryan Berringer, Program Manager, Clothes Washer Rulemaking, U.S. DOE. December 2, 1997.